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SPACE RESEARCH

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I. INTRODUCTION

Space research consists of the observation and study of objects and phenomena in the earth's high atmosphere and beyond. It includes direct and indirect measurement, theoretical and laboratory research, and the performance of fundamental experiments in space. In the foreseeable future it will include manned exploration of the moon and the nearer parts of the solar system.

Space research is not in itself a separate discipline of science. Rather, it calls upon a great number of the disciplines of physics, chemistry, and the biosciences. It includes astronomy, astrophysics, and many aspects of geophysics. Space research is concerned with the atmospheres of the earth and planets; their ionospheres; their electric, magnetic, and gravitational fields; the earth-moon system; the planets, comets, meteors, and other bodies of the solar system; the sun, stars, and galaxies; the particles, plasmas, electromagnetic radiations, and other phenomena of interplanetary, galactic, and intergalactic space. It includes the search for forms of extraterrestrial life, and the study of the behavior of terrestrial life forms under the conditions of space and space flight. Its ultimate and most exciting quest is for an understanding of the origin and fundamental nature of the universe.

Space research is not new. It is as old as astronomy. In fact, in many ways the space research of today may be regarded as an extension and enlargement of the field of astronomy. Viewed in this light space research has a history measured in thousands of years. It has claimed the attention of some of the greatest minds: Copernicus, Galileo, Kepler, Newton, LaGrange, Laplace, and Einstein, to name but a few.

Space research poses a tremendous challenge to the scientist. Earth-bound, located at fantastically great distances from the objects of his attention, hampered by the obscuring and distorting effects of his own atmosphere, the scientist has had to piece together the picture of the universe from the bits and snatches of light that reach his eye or instrument. In spite of these severe restrictions which limit his observations primarily to the visible and radio portions of the wavelength spectrum, scientists have pieced together a truly remarkable picture of the universe in which we live. But now, almost suddenly, there has opened before him by means of sounding rockets, satellites, and deep space probes, the opportunity to send instruments and eventually man himself above the earth's atmosphere to observe and measure in hitherto unseen portions of the wavelength spectrum, and to carry out direct explorations of the moon and the solar system. This opportunity brings with it the chance to enlarge, to clarify, to correct the present concepts of the universe. To take advantage of these opportunities requires the development and construction of intricate automatic equipment, the conduct of exceedingly complex launching, tracking, and telemetering operations, and eventually the performance of hazardous manned missions. But the rewards in the way of increased knowledge and practical applications to human welfare, are so great as to make the challenge irresistible.

High altitude rocket research first began in the United States in 1945 with the launching of the WAC Corporal rocket developed by the Jet Propulsion Laboratory. Early in 1946 V2 rockets were put to use for upper air research, and in the ensuing years large numbers were used in the exploration of the upper atmosphere. The Aerobee and Viking rockets were developed specifically to carry out high altitude experiments. The Rockoon technique, that is, the launching of a rocket from a large high altitude balloon, was developed to provide an inexpensive means of sending small payloads into the ionosphere. Small solid propellant rockets were adapted to the task of high altitude exploration. All in all, prior to the start of the International Geophysical Year on July 1, 1957 the United States had fired about 400 sounding rockets for exploring the upper atmosphere, investigating the sun, and performing various high altitude experiments.

Because of the proven power of the rocket sounding techniques, a rocket research program was introduced into the IGY effort. The rocket program was listed as a separate activity from the other disciplines of IGY, although it was clearly recognized that the rocket activity was not in itself a discipline, but rather included researches from many of the other IGY disciplines. It was found necessary, however, to keep the rocket effort in a separate category because of the special demands of the rocket itself, the requirements for special launching ranges, and the difficulties of making a completely routine and firm schedule for the rocket firings.

During the planning of the IGY rocket program, it became apparent that it might be possible to launch artificial satellites of the earth during the IGY interval. Because of the clearly foreseeable value of such satellites in the IGY program, the

International Committee for IGY recommended that consideration be given to including artificial satellite programs in the IGY effort. The result was that both the USSR and the U. S. undertook to launch instrumented earth satellites for geophysical and solar explorations during the IGY. It is now a matter of history that the first such launching took place on October 4, 1957 when the USSR placed Sputnik I in orbit about the earth. A review of the rocket and satellite research results through the end of the International Geophysical Year is given in Section II of this paper.

Out of the rocket and satellite activities of the IGY and the preceding decade there has developed an extensive technique of atmospheric and space research. No longer is the sounding rocket a mysterious and unfamiliar tool. No longer is the earth satellite or the space probe an unfamiliar device. There now exists a wealth of information on the behavior of the sounding rocket during flight, on the conditions experienced by instrumentation in the rocket during both the launching and coasting portions of the flight. In the case of satellites and space probes experience is less extensive than with the sounding rocket. Nevertheless there is enough information available to define with some assurance the design criteria that must be met by the instrumentation in such vehicles, and to prescribe adequate tests to insure that the equipment will survive the launching rigors and continue to function throughout the trajectory or orbit. The experience of IGY has shown the usefulness of international cooperation in satellite observation and has provided experience in organizing such cooperation. Based on this past experience, the techniques of space research are discussed in Section III of this paper.

To a large extent the past history of rocket and satellite exploration of the atmosphere and space has been only a beginning. Much larger and more versatile rocket vehicles are now under development. For more routine operations, relatively inexpensive vehicles are being developed. Tracking and telemetering networks are being extended and improved. Work is underway on improved power supplies, stabilization systems, new detectors, and more accurate guidance and control systems. With these advances both the intensity and the range of space activities can be increased. A description of current planned activities in space research is given in Section IV of this paper.

A large portion of space activities, particularly in future years, will be concerned with manned flight in space and manned exploration of the solar system. This is both a fascinating and an important subject, to which much attention is being devoted. In this paper, however, we shall not take up the details of manned flight and exploration.

II. PAST RESULTS OF SPACE RESEARCH

By liberating scientific disciplines from their earth-bound limitations, space research has resolved many long-standing problems and controversies. The rate of progress was accelerated in many scientific areas and in some cases completely new fields were unveiled.

For convenience, we shall divide the subject into several broad areas: Atmosphere, Ionosphere, Energetic Particles, Electric and Magnetic Fields, Gravitational Fields, Astronomy, and Biosciences. Actually the various areas are related in many complex ways, and the investigation of the various interrelationships is very important in itself. A brief discussion of each of the above areas is presented ahead of the results obtained from space research, in order to place these results in their proper perspective.

A. ATMOSPHERE

The existence of atmospheric pressure was unknown until Torricelli's invention of the mercury barometer in 1643. Perhaps equally important was the creation of the first vacuum chamber in the space above the mercury column. The rapid improvement of vacuum techniques during subsequent years, was evidenced by the spectacular demonstrations performed in 1654 with the Magdeburg hemispheres. But far more significant was the availability of a new and essential tool, namely the vacuum chamber with which the physics of gases could be studied. By the end of the 17th century the basic laws governing the distribution of pressure with altitude had been derived by Mariotte and Huygens. However, assumptions regarding mean molecular mass and temperature introduced considerable uncertainties in the numerical results, which were derived from the basic gas laws. Prior to the availability of rockets for upper atmosphere research, the atmospheric structure was accurately known up to about 30 km, as a result of balloon investigations. Although crude estimates regarding the structure of the upper atmosphere were available from meteor, ionospheric, and auroral studies, the atmosphere above 30 km was relatively unknown until 1946, when rocket soundings were initiated. As will be shown later rocket research has considerably increased our knowledge of the upper atmosphere. Nevertheless, many questions still remain unanswered concerning the origin, evolution, nature, spatial distribution, and dynamic behavior of the upper atmosphere; its relation to interplanetary space; its sources of energy; its relationship to surface meteorology; and its influence upon instrumented or manned space flight. Of interest from a longer range viewpoint are the analogous problems which are presented by the atmospheres of the other planets.

Rocket Results

Rocket measurements have provided a fairly complete and accurate picture of the atmosphere up to about 110 km. Results have also been obtained between 100 and 200 km. The temperature distribution with height exhibits a maximum of about 270°K at 50 km, a minimum of about 200°K around 80 km, a sharp rise in the E-region, leading to values of the order of 1500°K at 200 km. Up to about 70 miles (110 km) altitude, density and pressure both fall off by roughly a factor of 10 for every 10 mile (16 km) increase. Densities measured at 200 km above White Sands, and above Fort Churchill, Canada were found to vary by a factor of 5. Diurnal and seasonal effects were also detected at altitudes between 50 and 200 km. Rocket measurements show that the atmosphere is well mixed and maintains ground level composition up to 100 km, with the exception of lesser constituents such as water vapor and ozone. Above 100 km, diffusive separation takes place, with the lighter elements becoming more abundant. In addition, photochemical dissociation produces atomic oxygen and nitrogen. By 1952, enough rocket results had accumulated to compile the available information into a standard atmosphere, which was quite reliable up to 80 km. The results obtained during the International Geophysical Year will permit the formulation of a meaningful standard atmosphere up to at least 200 km and perhaps to 500 km.

Satellite Results

Satellite drag measurements were made at altitudes between 180 and 725 km. The densities obtained for the lower altitudes are in general agreement with rocket results, when seasonal and latitude variations are considered. Taken together the satellite and rocket measurements show considerable variation in upper atmosphere densities and temperatures with time of day and geographic position. This appears to be particularly true for altitudes above 220 km. (Fig. 1)

B. IONOSPHERE

Background

The growth of radio and electronics at the beginning of the twentieth century led inevitably to the discovery of the earth's ionosphere. This ionized region of the upper atmosphere has been investigated extensively from the ground on a world-wide basis by a method which is an extension of the experiments originally performed by Breit and Tuve in 1926. The method, which is similar to radar, is based upon the reflection of radio waves by the ionized regions. Ionospheric electron densities can be computed from these soundings; however, the height distribution of these densities was in some cases uncertain by as much as 100 km. This uncertainty arose partly from the extreme complexity of the analysis required, but mainly from the assumptions needed to interpret the discontinuities found in the ground recordings. Even though early observers knew that their data should be interpreted with caution, they felt fairly well convinced that the ionization was concentrated in separate layers which they called D. E. and F. Considerable information was nevertheless accumulated which revealed the general behavior of the ionosphere below 300 km, particularly its daily and geographical variations, and the influence of the 11 year solar cycle.

Rocket determination of typical electron density profiles, plus the recent availability of electronic computers have resulted in a greatly enhanced activity in the world-wide analysis of ground recordings. Fairly accurate electron density profiles can now be obtained up to the maximum of the F_2 region which occurs at approximately 300 km in middle latitudes. Typical daytime densities are 10^5 el/cc in the E-region and 10^6 el/cc in the F-region. Faraday rotation measurements made by reflecting radar echoes from the moon have shown that the total ionization content above F_2 maximum is in the daytime about 3 times greater than the columnar electron density from the ground up to F_2 maximum. At night this 3-to-1 ratio is increased to about 4-to-1. Whistler data give approximate densities between 100 and 1000 el/cc at several earth radii. Ionosphere problems exist in three broad areas, namely: (1) the accurate determination of the spatial and temporal variation of the ionospheric structure, (2) the explanation of the mechanisms responsible for the ionization, and (3) the propagation of radio waves in the ionosphere. A natural extension of this work will be the study of the other planetary ionospheres, including that of the moon.

Rocket Results

Electron density profiles for the 80 to 250 km altitude range are available from at least 10 and perhaps as many as 20 rocket flights. A few measurements were made at altitudes between 250 and 500 km by both Russian and U. S. scientists. These measurements show that the daytime ionosphere does not consist of separate layers; it was found instead that the regions of relative maximum ionization blend gradually together with only minor valleys in the ionization distribution versus height. Superimposed upon this continuum are occasional very high ionization gradients. Studies of rocket-to-ground radio propagation reveal considerable fluctuations in the received signals which are probably due to multipath transmissions resulting from inhomogeneity in the ionospheric structure. The absorption of radio waves has been accurately measured in the D-region and the collision frequencies calculated therefrom were shown to be at least three times smaller than was generally believed to be the case. The polar blackout was shown to be strictly a D-region phenomenon with no significant effects noted above 100 km. Two night flights conducted near the winter solstice showed that electron densities in excess of 10^6 el/cc were present in auroras, whereas densities of only 10^4 were present in the absence of auroral activity. Mass spectrometer studies in the ionosphere reveal that the most important positive ions are those of nitric oxide, molecular oxygen, and atomic oxygen. Above Fort Churchill it was found that as the altitude increases from 100 km to 150 km to 200 km the order of relative abundance of positive ions during the daytime changes from (O_2^+, NO^+) to (NO^+, O_2^+, O^+) to (O^+, NO^+, O_2^+); but at night, the NO^+ is more prevalent at the lower altitudes. (Figs. 2 and 3.)

Satellite Results

Although highly publicized, the satellite measurements of electron densities have to date been relatively crude. They were based primarily upon propagation studies and required the assumptions of uniform horizontal structure and single ray paths, both of which are known to be incorrect. Severe fluctuations in signals received from satellites, particularly from above F_2 maximum, are evidence of horizontal gradients and globular irregularities. Mass spectrometer data obtained from Sputnik III show that in the region from 250 to 950 km, the principal positive ion is mass 16, O^+, with a small percentage of mass 14, N^+.

C. ENERGETIC PARTICLES

Background

Early in the century it was discovered that an electroscope very slowly loses its charge no matter what precautions are taken to insulate it. It was at first assumed that this was caused by either leakage around the insulation or by radiation from radioactive materials in the earth's crust. A series of balloon flights conducted during the period 1911 to 1914 established that the discharge of the electroscope was due to a radiation of extraterrestrial origin. These observations may be regarded as constituting the discovery of cosmic rays. The fascinating problems presented by this new field led Karl Darrow to state: "The subject is unique in modern physics for the minuteness of the phenomena, the delicacy of the observations, the adventurous excursions of the observers, the subtlety of the analysis and the grandeur of the inferences." Following World War II, intensive studies with balloons resolved many of the questions associated with cosmic rays. These studies revealed that the primary cosmic radiation consists of protons, alpha particles, and heavy nuclei. The energy spectrum in the 1 Bev to 15 Bev range was determined by measurements at various geomagnetic latitudes, since in this energy range the penetration of cosmic rays is controlled by the orientation of the terrestrial magnetic field. Other techniques such as the observations of giant showers over areas of several acres show that the energy of cosmic rays can be as great as 10^9 Bev. Another group of particles with energies ranging from 10^3 to 10^6 electron volts was postulated in order to explain auroral phenomena. These particles were believed to be either protons or electrons. Although the absence of particles with energies between 1 Mev and 1 Bev was a principal enigma, many problems also existed in connection with the observable particles in the lower and higher portion of the energy spectrum. Typical questions were: the origin of the particles, the mechanism by which they acquire their energies, their effects on both animate and inanimate objects, and their detailed composition including the possible presence of anti-matter.

Rocket Results

Rocket work showed primarily that balloon measurements were adequate for many cosmic ray studies. It was established that the knee in the latitude curve was real and not due to air absorption cut-off. Rocket measurements of auroral particles showed that both protons and electrons are present in auroras; however, the auroras investigated to date with rockets were produced mainly by electrons with a few kilovolts of energy.

Satellites and Space Probes

Auroral electrons were detected by Soviet scientists in an experiment carried aboard Sputnik III. Within the auroral zone, in the energy range of 200 to 300 Kev, a flux of 10^4 particles per cm^2 per second was deduced as typical; while in the range 20 to 60 Kev a typical flux was 10^7 particles per cm^2 per second. U. S. satellites and space probes established the unexpected existence of the Van Allen Radiation Belt and partially mapped the region of space which it occupies. This belt appears to be composed of charged particles trapped in the magnetic field of the earth, and with energy levels ranging from those encountered in auroras up to those of cosmic rays. Measurements to date indicate that a portion of the more penetrating radiation in the inner region of the belt consists of protons. One explanation is that these protons are decay-products of fast neutrons of the earth's cosmic ray albedo. The remainder of the Van Allen Belt is probably of solar origin. Results from the Soviet satellite experiments appear to be consistent with those of Van Allen. The Soviet deep space probe "Mechta" has shown that a portion of the radiation in the outer region of the Van Allen Belt is composed of electrons with energies of a few tens of Kev. (Fig. 4.)

D. ELECTRIC AND MAGNETIC FIELDS

1. Electric Field

Background

The manifestations of atmospheric electricity as revealed by lightning and thunder have for thousands of years inspired more fear than scientific curiosity. In 1752 the electrical nature of lightning was demonstrated by Franklin in his celebrated kite experiment. In that same year Lemonnier observed the less well known and much less intense atmospheric electric field during fair weather. Investigations from the ground, balloons, and aircraft have shown that the earth's atmosphere can be considered as a leaky condenser of 200-ohm resistance through which flows about 1500 amperes of current. It is believed that the necessary upper atmospheric potential of about 300 kilovolts relative to the earth's surface is maintained by world-wide thunderstorm activity. Evidence of electrical storms on Jupiter indicates that similar phenomena exist on the planets.

Due to the high conductivity of the medium, it is unlikely that strong electric fields can be maintained within the ionosphere. Electric fields which might be postulated above the ionosphere are probably too small to be measured with present techniques. It is known, however, that a conducting body will acquire a charge in an ionized medium due to the high ratio of electron-to-ion mobility. This charge will produce near the surface of the body an electric field which was not present in the ambient medium. This local contamination of the medium must be taken into consideration when interpreting data obtained from an experiment in which a direct sampling of the medium is attempted. Charge on space vehicles could conceivably introduce appreciable electromechanical drag, particularly in the Van Allen Radiation Belt, and hence influence space flight.

<u>Rocket Results</u>

Electric fields of the order of 500 volts/meter were measured at the surface of a U. S. rocket, in the presence of a strong rf field produced by an antenna radiating a 4 Mc signal from the rocket. Since this field was about 20 times greater than expected from kinetic theory, it is believed that this enhancement was caused by the presence of the rf field. The field distribution was also found to be affected considerably by photoemission from the sun.

2. Magnetic Field

Background

Although magnetization was a phenomenon known to the ancient Greeks, it was considered chiefly as an amusing curiosity until the Chinese discovery of the magnetic compass during the Middle Ages revealed what turned out to be the most important application of magnetism for centuries to follow. The magnetic compass has been used by navigators since the eleventh century, but it was not until 1600 that Gilbert pointed out that the earth itself behaves as a giant magnet. During the past century magnetic observatories and surveys have provided rough maps of the magnetic field at the surface of the earth. The strength and orientation of the main field are subject to a slow secular drift. Geological differences introduce surface irregularities called anomalies. At a given location sensitive instruments reveal regular diurnal variations with superimposed irregularities, such as magnetic disturbances and storms. It is believed that these variations are caused primarily by electric currents in and above the ionosphere. However, due to the limitations of ground observations, definitive answers must await direct measurements from space vehicles. Although the magnetic field decreases in intensity according to the inverse cube of the distance to the center of the earth, its effect upon the atmosphere above 100 km increases rapidly with altitude. At much greater heights, where charged particles predominate, the earth's atmosphere is controlled by the magnetic field rather than by hydrostatic conditions. The problems associated with the magnetic field cover a far greater scope than indicated above. They range from basic questions concerning the very existence of the terrestrial field and its possible relationship to the initial formation of the earth, to speculation concerning the values of interplanetary and interstellar fields and the manner in which these affect cosmic rays and auroral particles.

Rocket Results

Measurements into and through the E-region, at the magnetic equator and in the auroral zones, have demonstrated the existence of electric currents in the lower ionosphere. These currents were found to be far more irregular than anticipated. The need for absolute magnetometers in space research has greatly stimulated the development of new types of magnetometers which have found great practical use on the earth's surface in military and civilian applications.

E. GRAVITATIONAL FIELDS

Background

Although the names of Newton and Einstein are usually associated with gravitation, this field has attracted the interest of, and received contributions from, a galaxy of scientific geniuses, including Galileo, Huygens, Euler, Bernouilli, Laplace, Lagrange, d'Alembert, and Hamilton. At the present time, the best theory concerning the nature of gravitation is Einstein's general theory of relativity, which asserts that gravity results from a distortion of space-time. This theory is, however, still far from being entirely satisfactory. For example, one does not know whether or not there is a "velocity of propagation" associated with gravitation; the relationship, if any, between the theory of the electromagnetic field and the gravitational field has not yet been discovered. Controlled experiments on an astronomical scale are required to test adequately the theory of relativity and to detect some peculiarity of the law which may lead to a more fundamental understanding.

A large group of problems falls within the framework of the Newtonian Law, such as the long-time stability of the solar system, the gravitational fields of the planets, the gravitational field of the earth, and the manner in which these fields affect space trajectories or reveal the internal constitution of the planets.

Rocket Results

In a broad sense, each rocket flight provides a new verification of Newton's laws. Rocket experiments, however, are too short to detect gravity anomalies or to contribute to our knowledge or relativity.

Satellite Results

The periods of artificial satellites are so much shorter than those of the moon and planets that we can observe in a few months effects which may require centuries to detect from the motions of natural celestial bodies. Studies of variations in the orbit of 1958 Beta (Vanguard I) indicate that the traditional concept of the earth as a spheroid equally flattened at both poles and bulging at the equator must be slightly modified. Actually satellite studies show that the earth is slightly pear-shaped, the longitudinal axis of the pear being along the earth's axis of rotation and the stem of the pear being in the northern hemisphere. These results have important implications regarding internal stresses existing within the earth and concerning the mechanical strength of our planet.

Very recent results, also derived from the orbit of Vanguard I, indicate that the bulge around the earth's equator is about 500 feet thicker than had been believed. The equatorial bulge appears to be greater than can be explained by the "hydrostatic equilibrium" concept, according to which the earth's mantle is flexible and bulges under the influence of the earth's rotation. It now appears that the bulge developed eons ago and that the mantle has since hardened and held its bulging shape.

F. ASTRONOMY

Background

The study of the heavens is an ancient science. During its early development, which lasted several millenniums, visual observations soon revealed a number of regular phenomena such as the annual procession of fixed constellations across the firmament. The major planets, although erroneously believed to be "wandering stars," were identified and named after the gods of Greek mythology. Great celestial events such as the occurrence of eclipses, the display of unusual meteor showers, and the appearance of comets were viewed with awe and recorded in the chronicles of history. Although astronomy expanded considerably during the past three centuries with the discoveries of the telescope and of the spectroscope, three decades ago this science was still limited to investigations in the visual spectrum. Radio astronomy, which developed primarily after World War II, opened a new and much wider window through which the skies could be seen.

However, a large portion of the electromagnetic spectrum of the universe is absorbed in the earth's atmosphere and can never reach an observer on the ground. The progress made in the field of rocket astronomy during the past decade shows that this last limitation is now rapidly being overcome. An unimpeded view of the universe is of course essential to the solution of many fundamental astronomical and cosmological problems such as establishing the distribution of energy and matter in space, or determining the origin, evolution, and destiny of the universe. (Fig. 5.)

Rocket Results

Rocket astronomy is being pursued vigorously by scientists in the United States. Their results, which have been obtained by both spectrographic and photometric techniques, fall into two broad categories: (1) the extension of previous knowledge, and (2) the opening and pioneering of new fields. The two examples which follow will illustrate work done to clarify already known phenomena. Radio fade-outs which first attracted attention in 1927 remained unexplained until a series of "push-button" rocket flights conducted during IGY conclusively demonstrated that hard solar X-rays were responsible for the enhanced D-layer ionization during these fade-outs. The 100 km uncertainity in the height of the emission layers causing the nightglow was reduced to within a few km by the first rocket flight instrumented for this measurement. In both cases very rapid progress was made by using rockets. to solve long-standing problems.

New fields were unveiled by rocket astronomy in solar, interplanetary and galactic studies. The solar spectrum, previously unknown below 3900 Angstroms has now been quite thoroughly investigated down to about 1 Angstrom. Below about 1800Å the continuum gives way to an emission line spectrum. The most prominent feature in the far ultraviolet region is the very intense Lyman alpha line of hydrogen at 1216Å. This radiation was also found to originate from all directions of interplanetary space. Very recently the sun was photographed in the light of the Lyman alpha line. Perhaps the most spectacular achievement was the unexpected discovery of nebulae observable only in the far ultraviolet region of the spectrum.

Satellite and Probe Results

Data concerning micrometeors were obtained from the United States satellite, Explorer I. These data indicate that 10^4 tons of meteoric material accumulate daily on the surface of the earth. Such meteor data provide basic information related to the composition and quantity of matter in interplanetary space. Also being measured are the penetration probability of meteors and their erosion rates for various surface materials. The effects of meteors must be accurately known in order to include adequate safety factors in the design of vehicles for space research and space travel. Effects of meteors can be detected also in the earth's atmosphere, as evidenced by correlations between meteor showers and rain precipitation or by the presence of ionization along meteor trails in the E-region of the ionosphere. The ionosphere, however, is produced primarily by the solar ultraviolet radiation, with occasional enhancements from X-rays, as established conclusively by rocket astronomy. These examples of the overlapping ramifications of the various disciplines are typical of the close relationship between the different areas of upper atmosphere and space research.

G. BIOSCIENCES

Background

New fields of medicine and biology have recently developed as a result of man's increased success in leaving terra firma, his natural environment. The age-old desire of overcoming gravity was first realized with the balloon ascent of Pilâtre de Rozier in 1783 in Paris. The Wright brothers in 1903 achieved the first dynamic flight with a heavier-than-air vehicle. The third step, namely flight without any support by air, has now come into being.

In conventional balloon ascents, the medical problems extend no further than oxygen deficiency and extremely cold temperatures. The numerous medical problems presented by flight in propeller-driven and jet-driven airplanes have, during the past 40 years, led to the development of aviation medicine. Space medicine, initiated in 1949, is concerned with the even greater medical problems presented by space operations. Typical problems are the effects of high acceleration, weightlessness, extended isolation, and harmful radiation. Many of the problems overlap into the field of space engineering, such as meeting the food and respiration requirements of astronauts. In a broader sense, the opportunity now exists to conduct fundamental life sciences research in extraterrestrial environments.

With the appearance of vehicles capable of reaching the moon and planets, there will also be the opportunity to look for evidence of extraterrestrial life forms. This is, in fact, one of the most exciting prospects of space research.

Rocket Results

Monkeys and mice, flown in a rocket from New Mexico in 1953 were subjected to accelerations up to 14g without any apparent harm. To determine factors which affect tolerance to weightlessness, one mouse had its balancing organs destroyed but was taught to do without them. This mouse appeared comfortable during the rocket flight, as shown by a movie taken in the rocket, while the other mouse with a normal sense of balance showed signs of distress indicated by its frantic motion. Soviet experiments of this type have included rocket flights and recovery of dogs, who showed no evidence of harm from their trips into space.

Very recently (28 May 1959) the United States launched two female monkeys 300 miles into space and brought them back alive and well. Telemetered data indicate that these monkeys suffered only slightly, if at all, from the stresses of take-off and the strange sensations of weightlessness. Several tiny samples of animal and vegetable matter were also carried in the nose cone for additional studies of the effects of cosmic rays and weightlessness. Some success in evaluating these effects may be achieved since the samples were recovered in good condition.

Satellite Results

The most spectacular biological experiment conducted in a satellite to date was performed by the Soviets. The flight of the dog "Laika" in Sputnik II has received such world-wide publicity, that further elaboration is hardly required in this summary.

III. TECHNIQUES OF SPACE RESEARCH

Experimenters are interested in rockets because rockets afford a means of carrying scientific instrumentation to altitudes not heretofore attainable. However, the transition from a laboratory bench to a rocket imposes many restrictions on the researcher and his equipment. In any except the simplest of sounding rocket launches, a considerable group effort is involved, and the experimenter finds that he is but one member of a vast team of workers, each with an exacting job to perform.

In designing the experiment the scientist must keep in mind that the capabilities of the vehicles to be used place limitations on the weight and size of the experimental installation, and on the trajectory or orbit to be obtained. Special requirements such as firing on a certain day or time of day, or the need to conduct a launching through an auroral display or at the time of a solar flare, may introduce serious complications into the firing operation.

Schedules must be planned and adhered to as far as is physically possible. Deadlines are set and must be met. The failure to meet a deadline usually involves the shift of the remaining portion of the scheduling and consequent failure to meet the planned launching date. The total time necessary for ground preparations and planning runs from about 1/2 year to 2 years.

Experimentation with small sounding rockets is a comparatively simple and inexpensive procedure and may be undertaken at a group level basis. The instrumentation and launching of a satellite or space probe, however, is a gigantic operation in complexity and expense, and can be undertaken only by tremendous teams, sometimes international in scope.

A. VEHICLE ENVIRONMENT

Sounding Rockets

In designing his equipment and in interpreting the data at a later date, the experimenter must bear in mind the various motions that a rocket undergoes during flight, and he must consider the effect these motions will have on his scientific instrumentation.

The normal accelerations experienced in a liquid rocket during flight run from a few times acceleration of gravity to perhaps as much as 20g. With fast burning solid rockets, however, accelerations from 50g to 100g may be encountered. Such facts must be kept in mind in the designing and building of equipment. During actual flight in a rocket, each component will have its effective weight increased by the number of g's acceleration being experienced. After the rocket motor has ceased burning, there is then a period of free fall during which all equipment is weightless. This portion of the flight is then followed, in the case of a sounding rocket or returning space probe, by a period of deceleration as the rocket reenters the appreciable atmosphere on its return to the ground. If equipment is to be recovered from the returned rocket, then it must be protected against both the atmospheric deceleration, and the high decelerations occurring during the rocket impact.

Rocket vehicles undergo considerable vibration while the rocket motor is firing. These vibrations occur over a wide range of frequencies, and ofttimes show severe resonance effects. Delicate equipment and sensors must be properly mounted in the payload in order to protect them from destruction by the rocket vibrations.

Unless post burnout stabilization is specifically provided, much of the stabilization built into a rocket will diminish or disappear after the rocket motor has burned out. Uncontrolled rockets usually undergo a variety of motions during unpowered flight, including spin, precession, and tumbling. The amount of precession or tumbling is often reduced by intentionally introducing a spin, sometimes by slightly canting the rocket fins so that during the powered flight in the lower atmosphere the action of the air stream on the canted fins will cause the rocket to spin.

The experimenter must remember that when the vehicle is in free fall the force of gravity is effectively absent, and he must consider whether the force of gravity is required for the operation of his particular equipment. It is sometimes necessary to introduce a centrifugal force field by rotating equipment, or by actually spinning the vehicle itself to give an effective gravitational field when the equipment demands it.

The decelerations experienced in rocket vehicles are usually inconsequential in their effects compared to accelerative forces and the effects of vibrations. Deceleration becomes important, however, when the experimenter wishes to recover his equipment. In this event, additional deceleration must be secured to reduce the impact velocity sufficiently to avoid destruction of the experimental equipment upon impact. This deceleration can be accomplished by deliberately destroying the streamlined aerodynamic shape of the rocket during its return to earth. Explosive charges, detonated at the desired time either automatically or by ground command, are effective in separating the vehicle into several portions which, due to poor aerodynamic shape, will fall to earth with reduced velocities. Location of the equipment to be recovered in an after portion of the rocket and disruption of the streamlined contours of a rocket generally permit retrieving the payload portion sufficiently intact that the scientific instrumentation can be recovered.

Spin and tumbling of a rocket vehicle is not always a drawback. The experimenter sometimes can take advantage of the spinning motion of the vehicle to give him the coverage necessitated by his instruments where scanning of the sky or earth is desired.

The speeds of high altitude rockets when traveling through the lower atmosphere are sufficient to cause considerable surface heating, especially on the frontal surfaces. Ordinarily, this heating is not severe enough nor of a long enough duration to affect the payload instrumentation seriously. The surface temperatures can rise to 400°Centigrade or more, and this fact must be borne in mind in the design of any exterior equipment, including radio antennas. Instruments which must extend into the air stream such as special probes, etc., must be especially designed with this heating requirement in mind.

An experimenter who is attempting to determine composition or make pressure measurements must bear in mind the fact that the gases from the rocket motor are a very disturbing influence in the environment of the vehicle and that at the higher altitudes above 100 kms the pressure of gases from the rocket are sufficient to disturb pressure measurements. Likewise, contamination from rocket gases will invalidate the data obtained from mass spectrometers and similar equipment.

A rocket in the upper reaches of the atmosphere is in a different environment of radiation than the experimenter on earth. The atmosphere of the earth absorbs a very considerable portion of the electromagnetic radiation of the sun. This protective action by the earth's atmosphere no longer exists in the upper atmosphere and the experimenter must plan ahead to be certain that the equipment he is using will function as intended under conditions of exposure to the complete gamut of solar radiation.

Satellites and Space Probes

Scientific equipment in satellites and space probes must live through the same sort of environment during the launching phase that equipment in sounding rockets must survive. In general, however, there is a significant difference. The satellite or space probe equipment need only survive the rigors of the launching regime and then operate properly thereafter. In the case of the sounding rocket, on the other hand, many of the measurements are made during the firing interval, and most of them are made while the rocket is still in the earth's atmosphere.

The useful functioning of a satellite or space probe occurs when the vehicle is in the outer reaches of the earth's atmosphere and beyond. Equipment must therefore be able to function under complete weightlessness, under the unrestricted radiation from the sun, in the presence of any plasmas or charged particle streams that may be encountered such as in the Van Allen Radiation Belt, and in the face of bombardment by micrometeors. The maintenance of a proper temperature regime within the satellite or space probe vehicle becomes a problem of major importance. Continued automatic operation over long periods of time places a special premium on extreme reliability.

Actually, experience with satellites and space probes is only in its beginning stages. However, it has been found that with great care and attention to temperature, vibration, vacuum, and the long term reliability problem, with adequate attention to survival during the launching period, and with very rigorous testing prior to the launching, it has been possible to build satellites and space probes that function as intended after being launched.

B. TRAJECTORIES AND ORBITS

The path in which a celestial body moves about the center of gravity of the system to which it belongs is called the orbit of that body. The term orbit is similarly applied to the paths of artificial satellites or space probes. When the path is traversed only once, it is often referred to as the trajectory of the body. For example, the path of the vertical sounding rocket which consists of a rise to a peak altitude and then an immediate return to earth is referred to as the trajectory of the rocket. Similarly, a space probe projected out along a path along which it escapes from the earth is sometimes referred to as the trajectory of the space probe.

The types of paths in space are determined by the gravitational properties of matter and Newton's laws of motion. In calculating the possible paths about the earth, for example, it is usual to assume that the mass of the earth is concentrated at its center. Such calculations give first order approximations to the true paths, which may then be corrected by more refined calculations when more accurate knowledge of the actual path is required. For the simple case of a body revolving about a gravitating mass point, or a perfectly spherical gravitating mass, it is found that the paths are conic sections, that is ellipses, parabolas or hyperbolas.

The most familiar one, an elliptical orbit, is closed on itself and is traversed repeatedly. The point of closest approach to earth is termed the perigee, that of the greatest distance from the earth the apogee. The circular orbit is obviously a special case of the elliptical orbit. The hyperbolic path is open, extending to infinity. The borderline path between these two is another special case, that of a parabolic path.

By definition, the velocity necessary to establish a parabolic orbit is termed "escape velocity". Hence, a vehicle launched into unpowered flight with escape velocity or greater will follow an open-ended path. One launched with less than escape velocity will assume an elliptical orbit. Escape velocity increases as the square root of the planet's mass, and inversely as the square root of the distance from the planet's center. Table 1 lists the surface escape velocities for a few planetary bodies of interest.

TABLE 1
Surface Escape Velocity

	Meters Per Second
Mercury	4,145
Venus	10,240
Earth	11,190
Moon	2,378
Asteroid Eros	Approximately 15
Mars	5,090

Satellite Orbits

Idealized satellite orbits are calculable by classical methods of physics. These calculations are of great value in planning the original orbit and in specifying the launching conditions. However, a satellite in orbit is subjected to a number of influences not taken into account in the simple approach mentioned above. Of these influences, two are conspicuous by their importance. The earth is not a true homogeneous sphere, but bulges at the equator. This produces noticeable perturbations of the orbit of a satellite, the principal effect being to cause the plane of the orbit to precess in space. Also, at heights within the atmosphere, air drag consumes some of the satellite's energy which eventually culminates in a return plunge of the satellite to earth.

The perturbations produced in a satellite orbit by gravity effects are of value in furnishing information concerning the shape of the earth and the distribution of its mass. Atmospheric drag yields information concerning the density of the atmosphere at satellite altitudes.

Table 2 lists the velocity, period, and estimated life of a satellite in a circular orbit.

TABLE 2
Satellite in Circular Orbit about the Earth

Height		Velocity		Approximate	Probable
mi	km	mi/hr	km/hr	Period	Life
0*	0*	17,940	28,900	84 min.	--
200	322	17,580	28,300	90 min.	Days to months
300	483	17,420	28,000	93 min.	Years
500	805	16,960	27,300	100 min.	Decades
1,000	1,610	15,700	25,300	2 hrs.	Centuries
22,000	35,400	6,800	10,900	1 day	Millennia

*Ignoring the atmosphere.

Calculations of the accuracy of velocity and guidance needed to project a satellite into a circular orbit, indicate that it is quite difficult to deliberately achieve even a nearly circular orbit. Indeed, far more often it is desirable to program a satellite into an elliptical orbit. A satellite in an elliptical orbit varies in altitude in its travels around the earth. This variation is often needed to accumulate data as a function of altitude as well as geographic location.

It can be proved that the orbital plane of a satellite must pass through the center of the earth. Thus the intersection of the orbital plane with the earth at any instant during flight is a great circle. The rotation of the earth, however, causes the path of the satellite's suborbital point to wind back and forth over the surface of the earth, since as the earth turns eastward the suborbital point tends to move westward. As a result, in general the track of a satellite will in time completely criss-cross the belt on the earth between the maximum northern and maximum southern latitudes reached by the satellite. As a matter of interest these maximum northern and southern latitudes (a) will always be equal, (b) will be the same as the inclination of the satellite's orbit to the earth's equator, and (c) can never be less than the latitude at which the satellite was injected into its orbit.

There are several satellite orbits of sufficient interest to merit special mention. First, a satellite launched due eastward above the equator into a circular orbit of 35,400 km height will appear to be stationary in the sky. This will be true since the period of revolution of such a satellite is 24 hours, exactly the period of rotation of the earth. Even if such a satellite were not launched due eastward, but were placed in a circular orbit of 35,400 km height, it would still have a 24 hour period of revolution. Thus as it appeared to move north and south of the equator it would at times drift to the west of the initial meridian and at other times to the east, remaining, however, within the general vicinity of its initial meridian.

In general, for a satellite moving in an elliptical orbit, the position of the perigee moves around the orbit. In the case of a near satellite of the earth, however, if the inclination of the orbit to the equator is about 63°, the perigee will remain at a fixed latitude.

A near satellite of the earth can be made to remain at all times in about the same position with respect to local sun time, by launching it into an orbit inclined at 83° to the equator. In such a case the plane of the orbit precesses at about the same rate that the plane of the twilight zone of the earth moves in space due to the revolution of the earth about the sun. If the satellite is injected into orbit in such a direction that it moves in a general westward direction, then the orbital plane will precess to the east at the same rate that the plane of the twilight zone turns.

A satellite launched at an angle just sufficient to cancel the eastward component of the earth's motion will have an orbit in which it passes over each pole of the earth during each revolution. If the period is not an integral divisor of 24 hours, such a satellite will in the course of time completely scan the earth's surface.

Sounding Rockets

The sounding rocket is generally fired with the deliberate intention of achieving the highest possible altitude. It is usually fired in an almost vertical direction with just enough inclination to fall at a safe distance from the firing site.

Many different sounding rockets are in common use. For heights below about 250 km, the experimenter can usually select a vehicle which will meet his payload and altitude requirements. Above this altitude the choice is quite limited and the vehicle cost rises considerably.

Space Probes

A space probe is a vehicle, not an earth satellite, that penetrates deeply into space far beyond the vicinity of the earth and the earth's atmosphere. In many respects the space probe may be regarded as a super altitude sounding rocket, but for convenience if the vehicle goes beyond, say, one earth's radius we call it a space probe instead of a sounding rocket. The orbits or trajectories of space probes may be highly elongated ellipses, or parabolas, or hyperbolas with respect to the earth. But once they have been projected far out into interplanetary space, the sun's gravity becomes the controlling factor in determining the path of the space probe. Thus, although at the present time it is possible to project vehicles along paths that are hyperbolic relative to the earth, so that they will escape from the earth, once the sun's gravity takes over as the predominant controlling influence the orbit becomes an ellipse relative to the sun. The ability to project a probe into a path that will be a hyperbola relative to the sun as well as relative to the earth will depend upon a considerably greater advance in rocket propulsion capabilities than we now have. The path of a space probe will also be modified if the probe comes within the influence of some other large gravitating body such as the moon or a planet. For the above reasons, a simple treatment of the paths of space probes is not possible. The specific path for a specific vehicle must be described in terms of its mission. Typical missions might be: simple escape from the earth; to orbit about the moon; to land on the moon; to orbit about a planet; to land on a planet; or to orbit about the sun.

The energy required to give a vehicle escape velocity from the earth is so great that space probes are large and expensive vehicles. Three or more stages are generally used and guidance may be required in one or more of these stages if it is desired to examine a particular region of space.

Highly specialized tracking and telemetry installations are required in order to receive data from the vehicle at the great distances involved.

C. GROUND SUPPORT ACTIVITIES

Extensive ground support facilities are necessary for the launching of sounding rockets and the recovery of data from them. These facilities include the means of handling, preparing, and firing the rocket, and for tracking the vehicle during its flight. Usually the data are recovered by radio techniques, for which it is necessary to have a telemetering station at or near the launching site. When recovery of records or equipment is necessary because of the type of instrumentation employed, then special recovery facilities must be available.

Satellites and space probes require supporting facilities located strategically throughout the world. These facilities must contain equipment for the tracking of the space vehicle, and for the reception and recording of the information telemetered back to earth. The launching location must contain the necessary handling, preparation and launching facilities, supported by an adequate and experienced staff.

Whereas the recovery of equipment from sounding rockets is now effected with a rather high degree of success, recovery of a satellite is a technological problem awaiting solution. Therefore, radio telemetry of information during flight is mandatory for satellites and deep space probes. In all cases the experimenter needs to know the altitude and location in space at which the data were obtained, and consequently precise tracking of the vehicle is necessary.

In numerous systems both optical and radio methods of tracking have been used. In general no one method is sufficient. Combinations of the two are usually used, and an excellent discussion of a system used in tracking sounding rockets and guided missiles is found in a description of the White Sands equipment*. For such applications the location of the optical and radar tracking facilities used must be precisely known with respect to the launching site. For a firing at a range such as White Sands the upper air experimenter can usually count on knowing the location of a rocket as a function of time to within 1/2 km.

For satellites and space probes the tracking net required is much more extensive than that needed in the case of a sounding rocket system. The Minitrack network used in connection with the U. S. IGY satellite program is an example of the sort of radio tracking net required for satellite observation.

The dozen or so stations equipped with Baker-Nunn cameras for use in the IGY satellite program furnish a good example of the sort of optical network needed for precision optical tracking of satellites and space vehicles. In the case of deep space probes only the largest of antennas can hope to maintain contact as the vehicle recedes into the depths of space. Antennas like the big dish at Jodrell Bank, or that at Goldstone in California

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*Hill, R. L., Tracking Guided Missiles with Radio Doppler, The Rice Engineer, 1, 6-15, December, 1952.

are required. In order to obtain optical sightings or photographs, the largest telescopes become necessary.

D. SCIENTIFIC INSTRUMENTATION

In general, conventional instrumentation as used in the ground based laboratory is not directly suitable for installation in rockets or satellites. Power requirements, weight, and space considerations are of primary importance in these instances, and will usually require that extensive redesign of the instrumentation be made to adapt it to inclusion in the rocket or satellite. In addition, it must be borne in mind that the accelerations, vibrations, and various motions of tumbling that a rocket or satellite undergoes may affect operation of the instrument. Detectors must be quite ruggedly built and, at the same time, be condensed into as small a space as possible while meeting scientific requirements. Especially in the case of satellites, due consideration must be given to the power requirements and the desired duration of the experiment. Additional consideration is necessary as to whether the instrumentation is to be operated in a pressurized package, or whether it can be subjected to the decreasing pressure and finally the ambient vacuum that will surround high altitude rockets or satellites. Further, the output of the instrumentation must be of such form, or modified to such a form, that it can be telemetered to earth for recording and eventual translation into useable information.

In the case of rockets or satellites carrying more than one piece of instrumentation, additional thought must be given to any interactions which may occur among the instruments involved. Can they operate simultaneously, or does the physical presence and operation of one instrument affect another instrument?

Once the scientific instrumentation has been developed or modified for use in a space vehicle, it must be given very extensive testing under the conditions expected to occur during its use in flight.

After the design and building of the instrumentation and the environmental testing of the prototype, the researcher must also determine the expected stability of the instrument, and provide for whatever inflight calibration may be needed. He will by this time have a knowledge of the accuracy and the expected precision of the instrument, but there still remains a problem. In first generation experiments the researcher may not know what magnitude to expect for the parameter being measured. In this case it is wise to select instrumentation capable of yielding information concerning the level of the parameter, preferably as a function of time, altitude, and geographic coordinates, and to seek detailed precise measurements in future flights after the level has been established.

Wherever possible, it is scientifically and economically desirable to test instrumentation intended for use in satellites by initial firings in sounding rockets. The successful operation of the equipment in a sounding rocket, and the successful interpretation of the data that is obtained, is a very useful prelude to inclusion of equipment in the much more expensive and prolific data-producing satellite.

In addition to requiring spatial position as a function of time, a great many experiments also require a knowledge of the vehicle attitude and orientation as a function of time for proper interpretation of the data. For instance, instruments determining pressure and density are sensitive to rocket velocity and exact attitude during flight, and a knowledge of the exact motions the rocket is undergoing is usually required to interpret the data correctly. Scanning experiments, for example experiments to determine the cloud cover of the earth or to map the ultraviolet radiations from the sky, require a knowledge of the direction of search at any particular instant.

Exact orientation, on the other hand, cannot usually be unambiguously obtained from the ground. It is often necessary to include equipment in the rocket or satellite which will measure the vehicle's orientation. In some cases the orientation can be obtained by careful interpretation of such data as the variation of radio signal strengths, variation of solar intensities, magnetic field strengths, etc.

In sounding rockets the inclusion of special cameras in the rocket is one of the most precise means of obtaining this information. However, recovery of the film is necessary to make use of this information.

E. INSTRUMENTATION WHICH HAS BEEN USED

Accurate scientific measurements require a foundation of preliminary measurements. The first step, of course, is that of detection. After detection, a rough establishment of level of intensity is necessary. It is then possible to design equipment to make accurate measurements of the physical quantity under investigation.

Table 3 lists instrumentation which has been used in rocket sounding programs. Only primary measured quantities are listed, so many equally important derived quantities, such as temperature, do not appear. Furthermore, there are instances in which listed quantities may also be determined indirectly as, for example, the determination of atmospheric constituents from the attenuation of

TABLE 3
Rocket Sounding Instrumentation

Measurements	Instruments	Remarks
Pressure	Bellows and Pirani gages, cold (Philips) and hot cathode ionization gages, alphatrons	Bellows gages measure down to 20 mm Hg, Pirani gages to 3×10^{-3} mm, Philips to 10^{-6} mm. Instrumental errors of several pct are increased to overall ten pct accuracy by winds, yaw, outgassing.
Density	Falling spheres	Less accurate than values derived from pressure distributions with altitude.
Winds	Angle of attack meters, grenades plus geophones	Qualitative data.
Sound speed	Grenades plus geophones	Used to obtain temperature.
Gas composition	Mass spectrometers, sample bottles	Mass spectrometers are used above ionospheric D-region, sample bottles up through this altitude.
Electron density	Radio frequency transmitters and receivers	Measure effective electron densities greater than 5×10^3 per cm^3 to accuracies of a few pct.
Ion density	Langmuir probes	Measure ion densities greater than 10^4 per cm^3 above 100 km altitude to accuracies of twenty pct.

TABLE 3 (Cont)
Rocket Sounding Instrumentation

Measurements	Instruments	Remarks
Ion composition	Ion mass spectrometers	Measure 0.8 to 47 AMU to nearest mass unit for densities down to 100 per cm^3, with 20 pct relative accuracy.
D-region conductivity	Gerdien tube ion collectors	Measure polar conductivities from 30 to 80 km within 10 pct.
Electric field and charge	Electric field mills	Measure fields of at least 1 v/m with 10 pct plus 2 v/m.
Solar and celestial radiations	Thermoluminescent phosphors, photon counters, photomultipliers, spectrographs, ionization chambers	Thermoluminescent phosphors give course resolution below 1300Å, photon counters intermediate resolution below 2000Å, spectrographs 1Å resolution above 1100Å.
Auroral particles and cosmic rays	Geiger, proportional and scintillation counters; ionization and cloud chambers; photographic emulsions	Recovery of film is required for cloud chamber photographs and emulsions.
Magnetic field	Coil, cathode ray and proton precession magnetometer	Rotating coils measure field component of at least 3 x 10^{-6} gauss to accuracy of 10 pct plus 3 x 10^{-6} gauss.

TABLE 3 (Cont)

Rocket Sounding Instrumentation

Measure	Instruments	Remarks
Airglow	Photon counters, photometers, photomultipliers	
Earth's albedo and aspect	Cameras, photocells	
Micrometeorites	Polished surfaces, microphones, scintillation counters	
Data recovery	Radio telemeter, film, emulsion, and recorder tape recovery	
Power sources	Batteries	

various solar radiations with altitude.

Table 4 lists experiments and instrumentation selected for use in satellites during the IGY Program.

<u>Selected Instrumentation Examples</u>

Instruments used in space vehicles are often subjected to extraneous disturbing influences. An easily appreciated example is that of atmospheric pressure measurements at the upper altitudes where outgassing and rocket motor exhaust may produce as great as or greater than the ambient pressure.

An ingenious method of overcoming this difficulty is to measure the pressure modulation induced on the side of a rolling rocket after it has been given an appreciable angle of attack. A pressure gage of rapid response, such as a Philips ionization gage, mounted on the sides of the rocket registers a sinusoidal pressure modulation of amplitude ΔP as the gage looks alternately forward and rearward.

From kinetic theory, the density ρ is directly proportional to the pressure change ΔP and inversely proportional to the rocket velocity v, according to the expression:

$$\rho = 0.182\ P/v \sin\theta \qquad [g/m^3;\ mmHg;\ km/sec]$$

A radio frequency mass spectrometer is an instrument which is highly suitable for the determination of the composition of

TABLE 4

International Geophysical Year Satellite Instrumentation

Measurements	Instruments
Density and geodesy	Radio and optical tracking systems
Electron density	Radio frequency transmitters plus receivers on the ground
Ion density	Ion traps
Ion composition	Ion mass spectrometers
Electric field and charge	Electric field mills
Magnetic field	Proton precession magnetometers
Solar radiations	Silicon-boron strips, ionization chambers
Atmospheric radiation balance	Special surfaces used as thermal detectors
Cloud cover	Photocells with infrared optics
Auroral particles and cosmic rays	Geiger and scintillation counters, ionization chambers, phosphors
Micrometeorites	Erosion strips, microphones, cadmium sulfide detectors, pressurized chambers with gages
Satellite internal temperature	Thermistors

TABLE 4 (Cont)

International Geophysical Year Satellite Instrumentation

Measurements	Instruments
Data recovery and tracking	Transistorized transmitters with magnetic core pre-modulators, miniature tape recorder plus command receiver for rapid play back.
Power sources	Batteries and solar cells

the upper atmosphere. By appropriate design the instrument can be used for the determination of neutral components or for ions of either polarity. These instruments have been built to cover ranges from 0.8 to 47 atomic mass units, with an accuracy of about 20% in argon to nitrogen ratio, and are useable to densities as low as 100 ions or 10^6 neutral particles per cm^3. Total weight is less than 22 kgm.

The proton precessional magnetometer is ideally suited to the quantitative measurement of very small changes in the earth's magnetic field, independent of vehicle aspect, to altitudes of approximately 3200 km. Absolute scalar flux density may be measured with an accuracy of 3×10^{-6} gauss. The instrument is useable to a minimum flux density of 0.09 gauss. The weight of this instrument is only 0.8 kg plus a power supply capable of supplying 150 watt-sec per measurement.

Positioning of Equipment

The firing of any but the simplest of rockets is an involved process requiring coordination of many steps according to a definite schedule. Instruments, which of necessity are likely to require attention in the last few hours before firing, should be designed to minimize this as much as possible, and the equipment should be installed in the rocket or satellite to be as easily accessible as possible. In all cases, the radio telemetering transmitter should be located in an accessible position for last minute testing and servicing.

In the case of satellite or space probe operations, the entire procedure is so very complicated that it is important to minimize the potential interferences with the preparation of launcing procedure. Thus it is highly desirable to have a number of spare units, so that if the satellite or probe should begin to malfunction during the launching operation, it will not be necessary to attempt to service the equipment. Instead, the satellite or probe can be removed and replaced with an entire new operating unit.

In many cases, even though the equipment is installed in the interior of the vehicle, contact must be made with the outside for the sensing elements used. Even observational type measurements, such as spectral studies and radiation surveys, require a window of some kind. In either case, the effect of protuberances or apertures upon the airflow about the missile must be considered. Also, the heating effects during the rocket's flight through the atmosphere must be considered by the experimenter with respect to location and type of material to be used for windows. Generally, small protrusions which are properly faired and symmetrically located (using dummies if necessary) do not disturb seriously the rocket flight performance. It is advisable to recess windows slightly or to use protective covers which are discarded at the desired time by automatic or command means. In the case of a satellite, a protective nose cone may be provided during the early portion of the launching, to be discarded after the denser atmosphere has been left behind.

F. LUNAR AND PLANETARY LANDINGS AND SATELLITES

Lunar Landings

Known and anticipated technical capabilities are such that it appears quite reasonable to expect space vehicles, capable of lunar impact, to be launched within five years. The local escape velocity from the earth at an altitude of 560 km is very close to 10.6 km/sec. The minimum velocity which will enable a vehicle to reach the moon is slightly less than this. Consideration of the variation of impact point on the moon as a function of variation of initial velocity, leads to the conclusion that mid course and/or terminal guidance are necessary if a reasonably good assurance of success is desired. For instance, if the original velocity is 0.010% too low impact will occur at the western limb of the moon instead of the center; if the original velocity is 0.014% too high, impact will occur at the eastern limb of the moon. Variations only slightly greater than this will result in a lunar impact not visible from the earth. Larger variations will result in a lunar miss. Velocity tolerance rises gradually to a value of about 91.5 m/sec as the initial velocity increases to about 10.7 km/sec.

The allowable path angle tolerance is about $4\frac{1}{2}^{\circ}$ at near-minimum initial velocities. This decreases rapidly with slight increase in velocity to a value of about $\frac{1}{2}^{\circ}$. Therefore, trajectories which permit large initial velocity tolerances are quite sensitive to initial path angle.

The transit time for a free flight lunar impact trajectory is also strongly sensitive to initial velocity. The minimum velocity trajectory takes about 5.5. days. An increase in the initial velocity of 1.0% results in a 2 day flight.

If it is desired to effect a soft landing on the moon with the intention of having instruments survive the impact, retro-rockets and additional guidance equipment will be needed to decrease the impact velocity to the desired amount. The approach velocity to the moon for unpowered free flight is a function of the initial velocity at the earth, but is never less than about 2.44 km/sec.

Circumlunar Flight

If a vehicle is launched to intersect the moon's orbit at a point ahead of the moon, and if the initial velocity of the vehicle was not above the earth's escape velocity, it is possible to take advantage of the moon's gravitational field to swing the vehicle about for a return trip toward the earth. The distance of closest approach to the moon is strongly dependent upon the initial conditions of velocity and angle, and may vary from a grazing passage to about 130,000 kilometers. The time for a flight of this nature is again strongly dependent upon the initial velocity and conditions, and varies from about 6 days to about one month.

G. ARTIFICIAL NONTERRESTRIAL SATELLITES

Lunar Satellites

It is possible to establish a vehicle in an orbit about the moon, if provision is made to reduce the approach velocity of the vehicle as it nears the moon. A velocity decrease of about 1.22 km/sec added near the point of closest approach is a representative figure of the magnitude involved.

Planetary Satellites and Landings

The various examples just discussed for the moon represent the simplest possibilities. Theoretically it is equally possible to consider probes, return trips, and satellites for the planets, especially so in the case of Mars and Venus.

The greater distances involved, and the uncertainty in the value of the astronomical unit, however, place very exacting requirements upon the guidance equipment, both in terms of accuracy and in terms of reliable operating life. Highly refined mid course and terminal guidance are needed.

IV. CURRENT AND FUTURE ACTIVITIES IN SPACE RESEARCH

The International Geophysical Year program included a considerable amount of space research. As a heritage from IGY there are Australian, British, Canadian, Japanese, French, Soviet and U.S. programs of rocket and related research of the upper atmosphere in space. During the International Geophysical Year cooperative rocket sounding and satellite observations were carried on. The tracking nets, telemetering stations, organizational arrangements, and experience obtained remain. Starting from this nucleus, the interest in actually participating in space activities is spreading.

To continue international collaboration in the scientific aspects of space research, the International Council of Scientific Unions has created a committee on space research. This Committee, COSPAR for short, has met to organize itself and to lay plans for its future activities. The United Nations has created an Ad Hoc Committee on the Peaceful Uses of Outer Space to study the problems and areas of interest involved and to report back to the General Assembly on various matters concerned with international cooperation in space activities. Individual nations are creating space committees, and initiating programs of research by means of sounding rockets and through observations of satellites and space probes.

To illustrate the growing effort in space research, this section reviews the activities in space science now under way in the U.S. National Aeronautics and Space Administration. The complete picture can, of course, be obtained only by adding to what is contained herein the programs of the other nations engaged in space science programs. Moreover, it would also be necessary to add other areas of space activity than space science, such as practical applications of satellites to meteorological surveillance or communications systems, and the effort to place man in space. These subjects are not taken up in this paper, which restricts itself primarily to the scientific research of the upper atmosphere and outer space.

A. IMMEDIATE PROGRAM

For convenience, this description of the present program activity has been divided into several areas; Atmopsheres; Ionospheres; Energetic Particles; Electric and Magnetic Fields; Gravitational Fields; Astronomy; and Biosciences, corresponding to those used in Section II. As mentioned in Section II, there is a considerable overlap among the different areas and, in fact, investigation of the various interrelationships is a very important part of the program.

(1) Atmospheres.

The atmospheres part of the program is concerned with the study of the structure, composition and motion of the earth's atmosphere, the relation of the upper atmosphere to surface meteorology, and the relation of solar activity to phenomena in the earth's atmosphere. The term atmospheres is used in the plural since the program is concerned not only with the atmosphere of the earth, but also with those of the planets Venus, Mars, Jupiter, etc., with the lunar atmosphere, if any exists, and with the solar atmosphere, which many believe to extend throughout much of the solar system.

The immediate plans include extensive and intensive studies of the structure and composition of the earth's atmosphere from 80 km to several hundred km by direct measurements with sounding rockets and with satellites. Diurnal, latitudinal, and temporal variations in these parameters will be studied and will be correlated with energy and momentum balances in the earth's upper atmosphere. Models of the earth's atmosphere will be formulated for (a) providing basic data needed in understanding ionospheric, auroral, and other phenomena, and (b) providing guidance in the study of the atmospheres of other planets.

Atmospheric studies to heights of 80 km will include scores of synoptic rocket flights and several cloud cover satellites to establish the relationships between surface meteorology and the structure and dynamics of the upper atmosphere.

A composite radiation satellite initiated under IGY sponsorship carries an earth's thermal balance experiment for the determination of the thermal radiation transmission characteristics of the atmosphere. The next-to-last Vanguard satellite experiment was of similar nature.

Micrometeorite experiments are to be carried on those satellites which have been scheduled for flight in the next year.

A satellite for the determination of the atmosphere's composition and density at altitudes between 220 and 1000 km is now under design with the launching planned for 1960.

The sounding rocket program includes units carrying pressure gages and mass spectrometers and experiments for the study of upper atmosphere winds by the tracking of visible trails, using sodium vapor, for example.

An inflatable sphere 3.65 m (12 feet) in diameter will be orbited to measure the air density at altitudes of about 650 km.

(2) Ionospheres.

The ionospheres portion of the program is concerned with the portion of the atmosphere that is electrified. At the present time, we have a fairly complete knowledge of the earth's ionosphere up to the E region at 100 km, a less complete understanding of the ionosphere between the E region and the F region maximum at about 300 km, and only scattered information about the ionosphere at higher altitudes. The current planning is aimed at exploring the ionosphere out to its farthest reaches, and toward pinning down the fluctuations in the ionosphere with time of day, season, sunspot cycle, and geographic position.

The immediate program is concerned with obtaining electron density profiles at altitudes above the F_2 layer by inclusion of proven propagation experiments in space probes. Concurrently latitude and temporal variations of this parameter will be obtained by use of orbiting satellite beacons. A topside ionospheric sounder in a satellite will be used for synoptic studies of electron density in the outer ionosphere. This technique promises lesser ambiguity than that obtainable from satellite beacons. The present knowledge of electromagnetic propagation will be extended by inclusion of very low frequency receivers in satellites and space probes. Ion spectrum studies will be extended to lower mass numbers and higher altitudes by inclusion of r.f. mass spectrometers in space probes and satellites. Direct measurements using devices such as antenna probes, ion probes, and electric field meters will be made in rockets and satellites, to better define ionospheric structure and to study the interaction between the ionosphere and space vehicles.

(3) Energetic Particles.

The energetic particles program is concerned with cosmic rays, the Van Allen Radiation Belt, and the particles causing the auroras in the earth's atmosphere. A major item of interest will be the distribution of energetic particles throughout interplanetary space.

In the near future the measurement of energetic particles will be pursued with satellites and rockets in the vicinity of the earth and with interplanetary probes. These measurements will be aimed at determining the interactions of these particles with the earth's atmosphere and field, their interactions with interplanetary fields, the types and energies of these particles, their spatial distribution, and the origin of the energetic particles.

Probes and satellites scheduled for launching in the immediate future include specifically measurements of the cosmic ray intensity in interplanetary space; of time and latitude cosmic ray intensity variations; of the composition and spatial extent of the Great Radiation Belt; of the cosmic ray energy and charge spectrum; and of the nature of the particles producing auroras.

Efforts are underway to carry emulsion blocks in recoverable payloads to obtain further data on the nature and intensity of the energetic particles encountered at extreme altitudes.

(4) Electric and Magnetic Fields.

The study of the electric and magnetic fields in space is an important part of the developing NASA program. Particular interest focuses on the study of magnetic fields in view of their role in trapping the particles that comprise the Van Allen Radiation Belt. It is of especial interest to determine what the magnetic fields of the moon and planets are like, and to compare them with the earth's magnetic field in strength and character.

The immediate magnetic field program includes the use of sounding rockets, satellites, and space probes to carry magnetometers for the investigation of the existence of ring currents above the ionosphere during magnetic storms, for the investigation of ionospheric currents, and radiation belt currents, for measuring electric currents and the form of the earth's field at great distances, for the study of interplanetary fields, and the moon's magnetic field.

Of particular interest in this connection is the development of the rubidium vapor magnetometer, which can be used to measure weaker fields than can be measured with the proton precessional magnetometer discussed in Section II E 5 above.

(5) Gravitational Fields.

The opportunity to perform experiments with satellites and space probes provides the scientist with a means of performing experiments on an astronomical scale, which should be of great benefit in gravitational studies. One of the first experiments of this kind was the simple observation of the satellites that had already been launched and from which improved values for the oblateness and shape of the earth have been obtained.

Studies are now being made on existing satellites with the object of determining the low harmonics of the earth's field from tracking data.

Design studies have been started on a special geodetic satellite which will be capable of refining the observations on the harmonics, and of determining intercontinental distances with high precision. It should be possible to carry the study of the form of the geoid much further than has been possible to date.

It is planned to put in orbit a satellite carrying a very precise clock in order to test Einstein's general theory of relativity which predicts a change in the clock's speed depending upon the strength of the earth's gravitational field. Studies on the atomic frequency standards which show promise for use as the clocks for this experiment are under way.

(6) Astronomy.

The astronomer will now have the opportunity in satellites and observatories orbiting above the earth's atmosphere to observe in the wavelengths that do not get through to the surface of the earth. The present plans include observations in gamma ray, X-ray, and ultraviolet wavelengths. For such purposes a stabilized satellite observatory is now under development.

The immediate program will continue and extend to the southern sky the survey of the newly discovered nebulosities in the far ultraviolet by means of rockets. These measurements are being undertaken to determine the nature and sources of these emissions. Concurrently stellar photometry measurements will be made in the near and far ultraviolet spectrum region to extend magnitude systems to the ultraviolet. Emphasis is being given to extending observations into the previously unexplored far infrared and high energy gamma ray spectral regions by means of scanning satellites and rockets. Apart from their intrinsic value, these surveys are essential as ground work for the satellite observatory program.

Studies of the solar ultraviolet and X-ray spectra will be extended to include long term variations, line profiles, distribution across the disk, and the spectra of the coronal X-ray flux. These studies will be carried out in a series of rocket firings and with satellite-borne pointing devices.

Deep space probes will be used to determine the nature of the interplanetary medium.

Satellites will be used to map the emissions of the high atmosphere which arise from charged particle interactions and photochemical reactions.

(7) Biosciences.

In the area of biosciences the opportunity now exists to do fundamental researches on the behavior of living organisms in space under the conditions of space and of space flight.

The major effort in biosciences is presently devoted to the support of Project Mercury, the man-in-space program.

In this program there are studies of life support systems and the psychology and physiology of space flight, as well as the experimental program for flights of animals leading up to the first manned flight. Rocket flights of varying length preceding orbital flight are planned.

Evenually, space probes will provide the scientists with the means of seeking extraterrestrial forms of life. This is one of the most exciting prospects of space research.

B. VEHICLES FOR THE PROGRAM

At the present time, except for the Vanguard vehicle it is necessary to use for satellite and space probe launchings vehicles that were designed for other purposes.

Other existing vehicles are the Juno II, the Thor-Able, the Thor-Hustler, the Atlas, and the Atlas-Able.

Vanguard is the three stage vehicle designed for the US IGY effort. At launching, the Vanguard weighs approximately 11 tons. The first two stages use liquid propellants to boost the third stage and payload to orbital altitude. After the desired altitude is reached, the solid propellant third stage accelerates the payload to orbital velocity. Several of the Vanguard stages appear in other vehicles currently in use, such as Thor-Able and Atlas-Able.

Vanguard, as originally designed, is capable of placing a 21 1/2 pound satellite into a 300 nautical mile orbit. The cloud cover satellite launched this Spring was typical of the sort of payload that can be launched with the Vanguard. There is a Vanguard 50 pound satellite planned, using an advanced solid third stage. This payload will carry experiments on cosmic rays, solar radiation, meteors, and the radiation inbalance in the earth's atmosphere.

Juno II is a four stage rocket similar to the Jupiter-C which placed the first US IGY satellite, Explorer I, into orbit. Juno II employs the Jupiter IRBM missile as its first stage. Stages 2, 3 and 4 are made of clusters of solid rockets, which accelerate the payload to orbital velocity. These latter stages are spin stabilized.

The Juno II is capable of placing payloads of about 100 pounds in a 300 nautical mile orbit. It has been used for moon probe launchings. In particular, it was used for Pioneer IV with which the US established its first solar satellite. A number of Juno II launchings are scheduled to occur over the next year for satellite experiments.

Thor-Able uses the Thor IRBM as a first stage and a Vanguard second stage (Able). At launching, the Thor-Able weight is approximately five times that of Vanguard and greater payload capability is therefore provided. The two stages (Thor and Able) provide orbit capability. Several other versions are available; Thor-Able 1, which employes the Vanguard solid third stage, and Thor-Able 2, which uses the high performance solid third stage developed for future Vanguard launchings. There are also the Thor-Able 3 and the Thor-Able 4, which as vehicles, are essentially similar to Thor-Able 3 with only minor differences in payload and guidance arrangements.

The Thor-Able can place 200 pound payloads into a 300 mile orbit and can probe to the moon and near planets with small payloads. Thor-Able 1 carried Pioneer I some 70,000 nautical miles away from the earth. Some additional Thor-Able vehicles are scheduled for satellite and space probe launchings.

Thor-Hustler is the Thor IRBM combined with a liquid propellant stage employing the Hustler engine. The Hustler second stage contains nearly twice the weight of the propellants carried by the Vanguard second stage (Able) and Thor-Hustler therefore has increased mission capability over the Thor-Able.

Thor-Hustler, while essentially a test vehicle to develop the Hustler upper stage, is also being used for satellite payload experiments.

Atlas is included in this list, since it is capable of placing payloads into orbit as a single stage vehicle. The Score satellite launched last December is an example.

Atlas, as a single stage, can launch a payload of 150 pounds to a 300 mile orbit. Project Mercury will use the Atlas for orbital flights of the manned satellite capsule. To do so, some modifications of the Atlas will be undertaken and it will be capable then of launching more than 2000 pounds into an orbit at altitude somewhat over 100 miles.

Atlas-Able uses a Vanguard second stage. A third stage is also used; this is the high performance solid fuel rocket which was developed for the Vanguard. The Atlas-Able is capable of imparting high enough speeds to 200 pound space probe payloads to cause them to escape from the earth.

The family of vehicles just described will be used for the program in the immediate future. Supplementing these are vehicles which are part of the U.S. National Space Vehicle Program. These vehicles are now being developed to carry our space projects for the forthcoming years.

NASA is developing a 4 stage, solid propellant satellite vehicle which will be capable of carrying about 150 pounds into a 300 mile orbit. Called the Scout, this vehicle will be much more economical than existing vehicles and will satisfy many of the requirements of the scientific program. It should be useful in support of international cooperative efforts.

NASA is also undertaking the development of the Delta. Basically, Delta will have the same 3 stage configuration as Thor-Able which has already been used by NASA and the Air Force in several deep space probes. The main new features of Delta are:

1. An improved radio-inertial guidance system;
2. Active guidance and control during longer coasting periods between second stage burnout and third stage ignition. The added coast period will mean maximum velocity at higher altitudes.

The Delta is an interim launching vehicle for use in 1960 and 1961 until some of the larger boosters capable of launching several tons of payload are developed. Delta should be capable of putting 250 pounds in a nominal 300 mile earth orbit or sending a 100 pound payload on a deep space mission. It will use a modified Thor as a first stage. The second stage will house the guidance and will be powered by a reworked Aerojet-General engine similar to that used for the Vanguard second stage or for the Able stage of other vehicles. First and second stages will be liquid fueled while the third stage will be a solid propellant rocket built by the Allegheny Ballistics Laboratory. Delta will stand about 90 feet high, weight over 100,000 pounds loaded, and develop more than 150,000 pounds of thrust. NASA plans for the vehicle include launching several deep space missions and satellites from the Atlantic Missile Range in Florida, and launching polar orbital satellites from the Pacific Missile Range, California.

As a first vehicle with large payload capacity, NASA has under development the Vega, a 3 stage vehicle using a modified Convair-Atlas as a first stage. The second stage will incorporate a modified General Electric engine which was used as the Vanguard first stage. The third stage will be a Jet Propulsion Laboratory rocket using storable propellants. The Vega vehicle will make it possible to put several tons in a 300 mile orbit and to send about 1000 pounds to the vicinity of the moon. Later vehicles in the program include the Centaur, Saturn, and Nova. Centaur is similar to Vega in concept except that the second stage will use high energy propellants. The first stage of the Saturn vehicle is under development by the Army Ballistic Missile Agency and will use a cluster of existing rocket engines to give over 1,000,000 pounds of thrust. The Nova vehicle will be based on a single chamber rocket of over 1 million pounds thrust. This large single chamber engine is being developed by the Rocketdyne Division of North American Aviation under NASA contract.

C. SCHEDULING

Table 5 indicates the numbers of the sounding rockets, satellites and probes presently scheduled for the space research program for the period July 1959 to December 1960. In preparing and planning a space research program it has become apparent that the scheduling of the major satellite and probe vehicles must be carefully correlated with the range capabilities available in the U.S. The larger vehicles must be launched from either the Atlantic Missile Range or the Pacific Missile Range. Discussion of these matters is continued in the following section.

TABLE 5

LAUNCHING SCHEDULE SUMMARY
SPACE RESEARCH EXPERIMENTS

July 1959 - December 1960

PROGRAM	ROCKETS	SATELLITES	PROBES
Atmospheres	53	2	3
Ionospheres	4	2	2
Energetic Particles	11	3	5
Electric and Magnetic Fields	32	3	5
Astronomy	20	3	3
	120	13	18

The totals shown are for experiments to be carried. In general, sounding rockets carry single experiments, while satellites and space probes carry several experiments in a payload.

Gravitational field experiments are being prepared for launching in 1961.

It will be noted that approximately 100 sounding rockets were scheduled for this period and somewhat more than 30 satellites and space probes. These units will constitute a major workload for the ranges and their firings will have to be carefully distributed among those scheduled for military programs and test operations. In scheduling satellites and space probes an effort has been made to maintain a reasonable balance among the various programs outlined above. At this time, scheduling is, of course, affected by vehicle availability, the ability to prepare payloads for the specific experiments, and the fact that it is necessary to obtain working results before scheduling follow-on experiments.

D. SUPPORTING FACILITIES

The major supporting facilities required for the conduct of a space research program are the following: Launching stations, electronic and optical tracking equipment; data collecting systems; communications and data transmission networks to return the data collected to a central point; and computing facilities for orbital calculations and data processing.

As a result of the IGY program and the early satellite and space probe planning, there are many supporting facilities already in existence. For launchings, there are the military establishments located at Cape Canaveral, Florida, at the Atlantic Missile Range, and those installed in California at Vandenburg Air Force Base and the Pacific Missile Range. In addition to these major facilities which can handle the large vehicles used for satellite and space probe launchings, sounding rocket facilities are available to the space research program at Fort Churchill, Canada; White Sands, New Mexico; and Wallops Island, Virginia. There are also numerous mobile sounding rocket launchers in existence, and launchings have been and can be made from various naval vessels. These facilities will be used in conducting the U.S. National Space Research Program.

For tracking purposes, Figs. 7, 8, 9, and 10 indicate the locations of the Minitrack network, the Baker-Nunn stations for optical tracking, and some of the Microlock and space probe receiving stations. These are available for use in acquiring data and for tracking and finding the space coordinates of satellites and probes. The facilities are capable of tracking the larger vehicles in their orbits or on space probe missions. Data collection is generally centralized at the same locations, so as to minimize the number of independent stations that must be supported. Fig. 11 indicates the major facilities; the name, the number, the units, major equipment units located at these facilities, and the general function that these particular facilities include. Communications and data transmission are generally handled by networks made up of military lines and leased lines of the commercial communications organizations. By this means it is possible to return tracking data to the central computing point in sufficiently rapid manner so that orbital determinations can be carried out for prediction purposes so that antennas and cameras can be trained on the proper point in space for the acquisition of additional data.

Telemetering data are generally acquired at the various stations and tape recorded, and the tapes are usually mailed back to the central data processing center. Data processing and computation systems are available at a number of locations where they have been used part time to support the specific programs in the past. There are presently being consolidated under the national program for satellite and space vehicle tracking two major facilities, one under the NASA, and one under the direction of the Department of Defense. If we examine the needs for additional facilities in terms of the scheduled program, we find that tracking and data collecting are two major areas in which the existing facilities must be supplemented. Plans are already under way to expand the coverage of the Minitrack network so that it will be capable of handling polar orbits as well as relatively low orbital inclination orbits, and to add space probe tracking stations so that essentially continuous coverage of space probes can be considered available with less disruption than in the past to such operations as that of the radio astronomy station at Jodrell Bank.

V. INTERNATIONAL COOPERATION IN SPACE RESEARCH

The value of international cooperation in science has long been recognized in the field of astronomy. Its potentialities for geophysics and related researches were clearly demonstrated in the International Geophysical Year effort. As part of that effort the rocket and satellite program made good use of international cooperation, particularly in the simultaneous firings of sounding rockets, and in the mutual tracking of satellite vehicles. The future of space research may be expected to profit greatly from international efforts, and in some cases to require such cooperation. It seems worthwhile, therefore, to list briefly some of the areas in which international cooperation is desirable.

1. Simultaneous launchings of sounding rockets in the study of the upper atmosphere, the aurora, the ionosphere, magnetic storms, and other phenomena that may be expected to vary with geographic position should be of great value.
2. Mutual assistance in the design of experiments and in the preparation of payloads for rockets, satellites and space probes may be desirable.
3. International cooperation in the tracking of satellites and in the reception of telemetering data from them is highly desirable.
4. An international program for the observation of radio signals from satellites for the purpose of investigating the ionosphere is required in order to solve existing problems on the ionosphere.
5. International cooperation in laboratory and theoretical research in areas supporting or related to space research is highly desirable.

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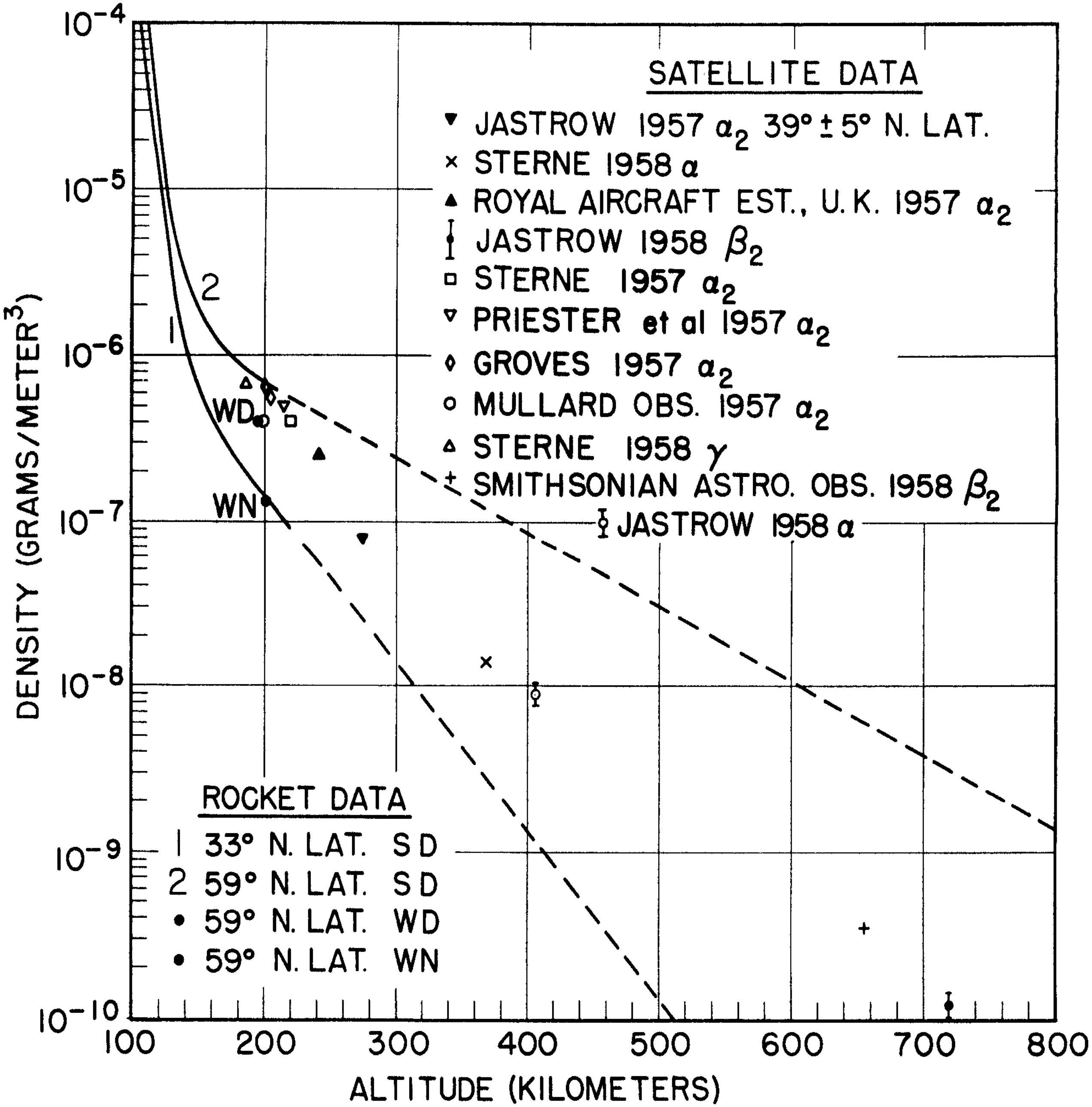
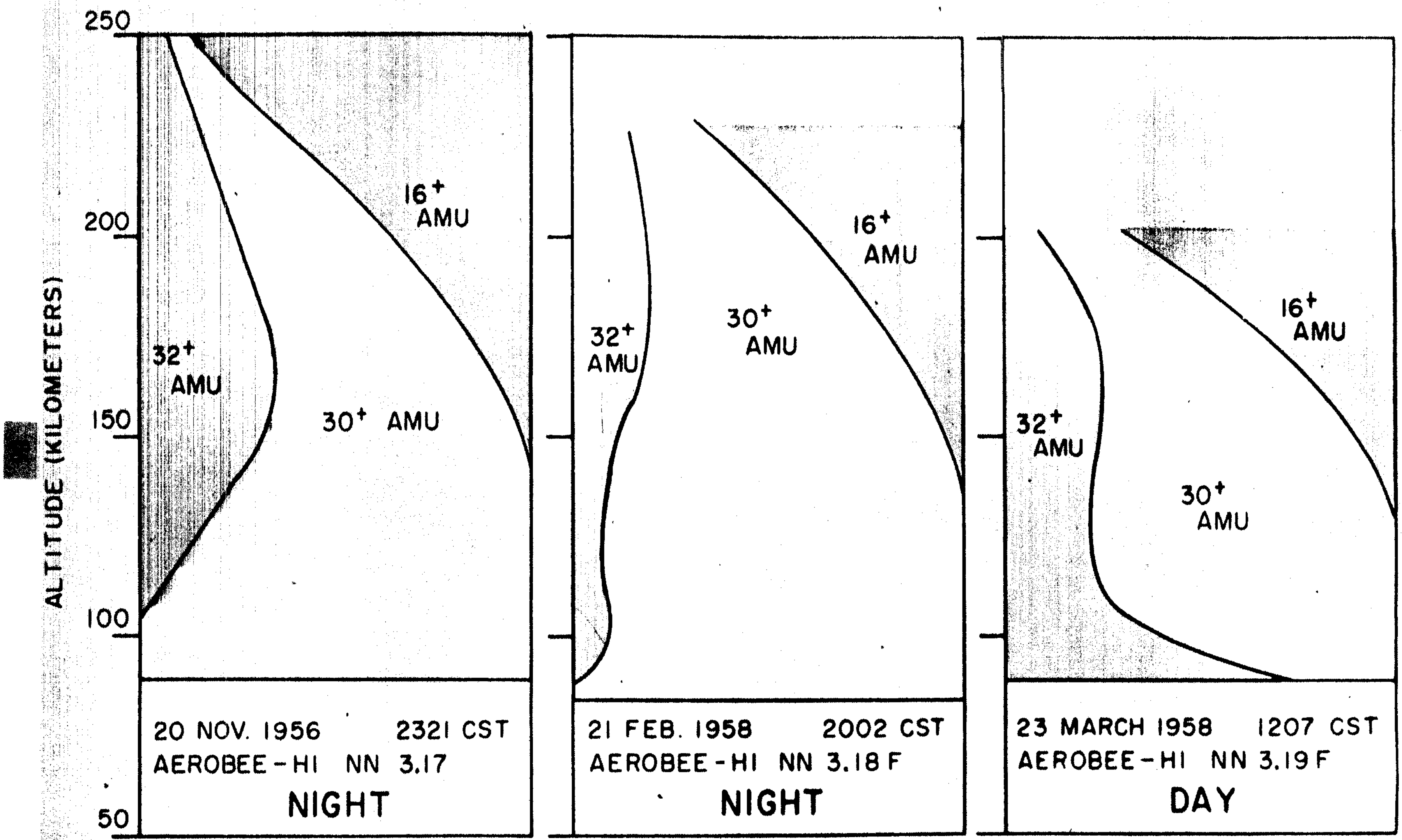


AIR DENSITIES FROM ROCKET RESULTS AND SATELLITE DRAG MEASUREMENTS

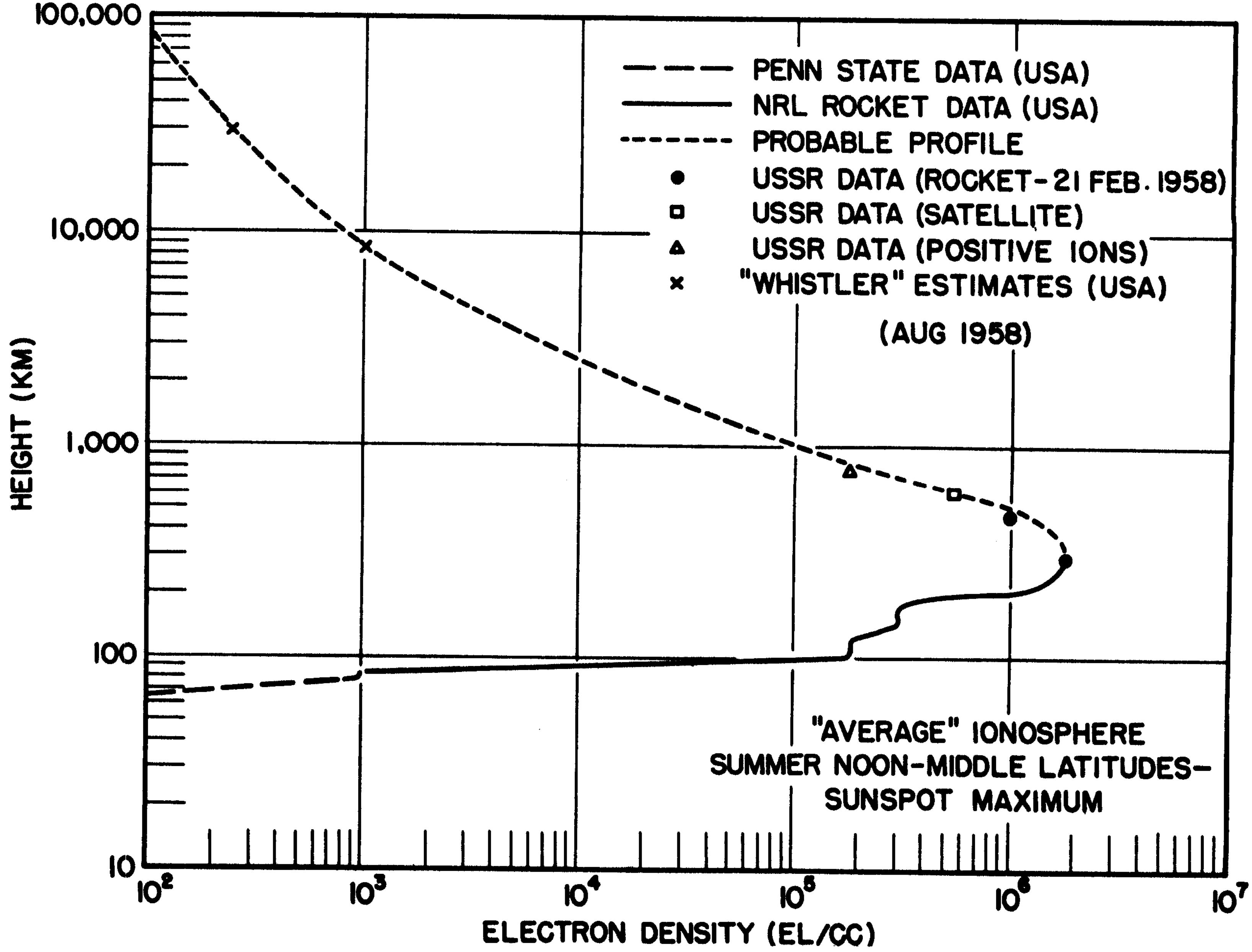
FIGURE 1



DISTRIBUTION OF THE MAJOR POSITIVE IONS ABOVE FORT CHURCHILL, CANADA.

RELATIVE ABUNDANCES OF O^+, NO^+, O_2^+

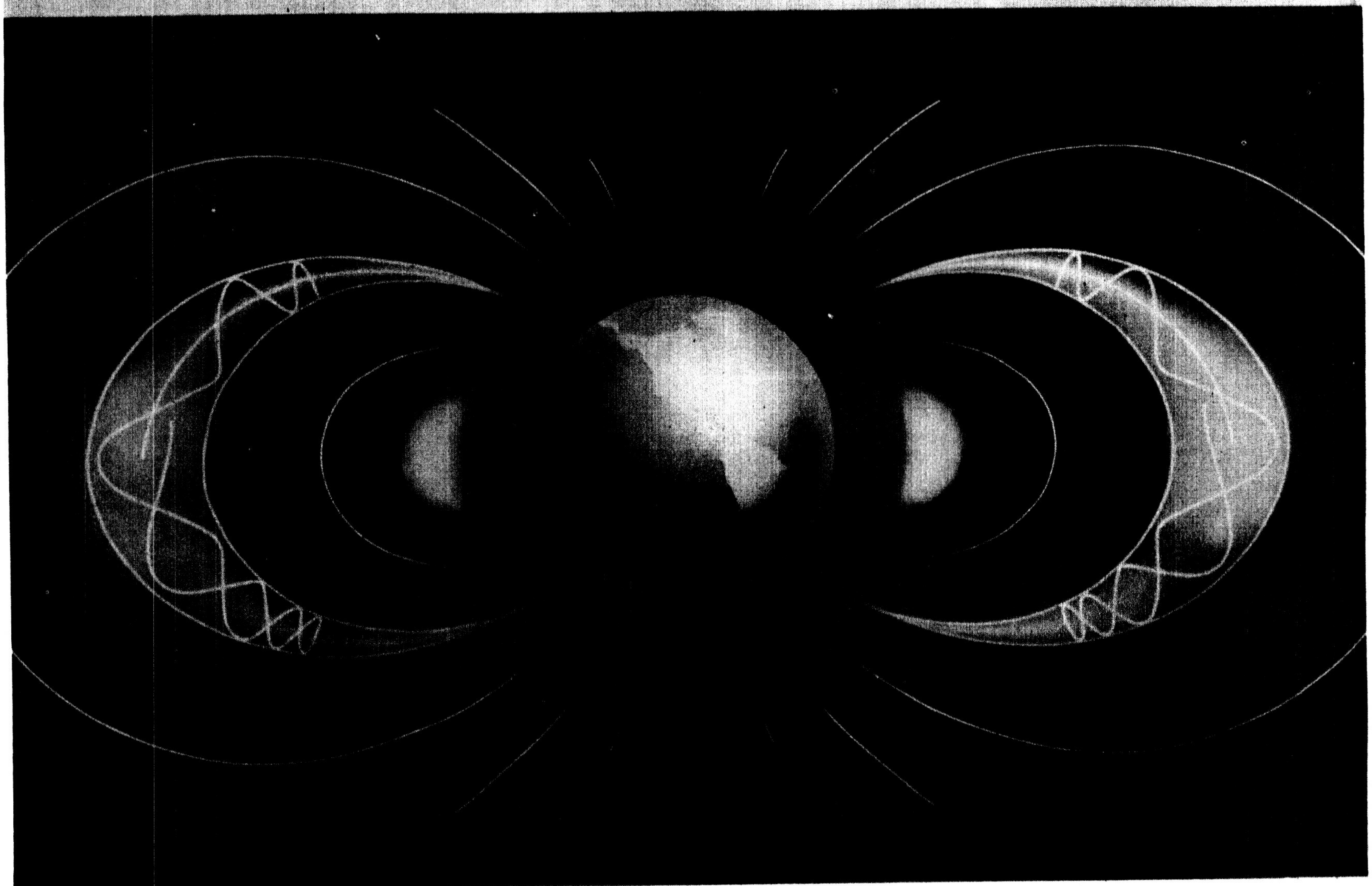
FIGURE 2

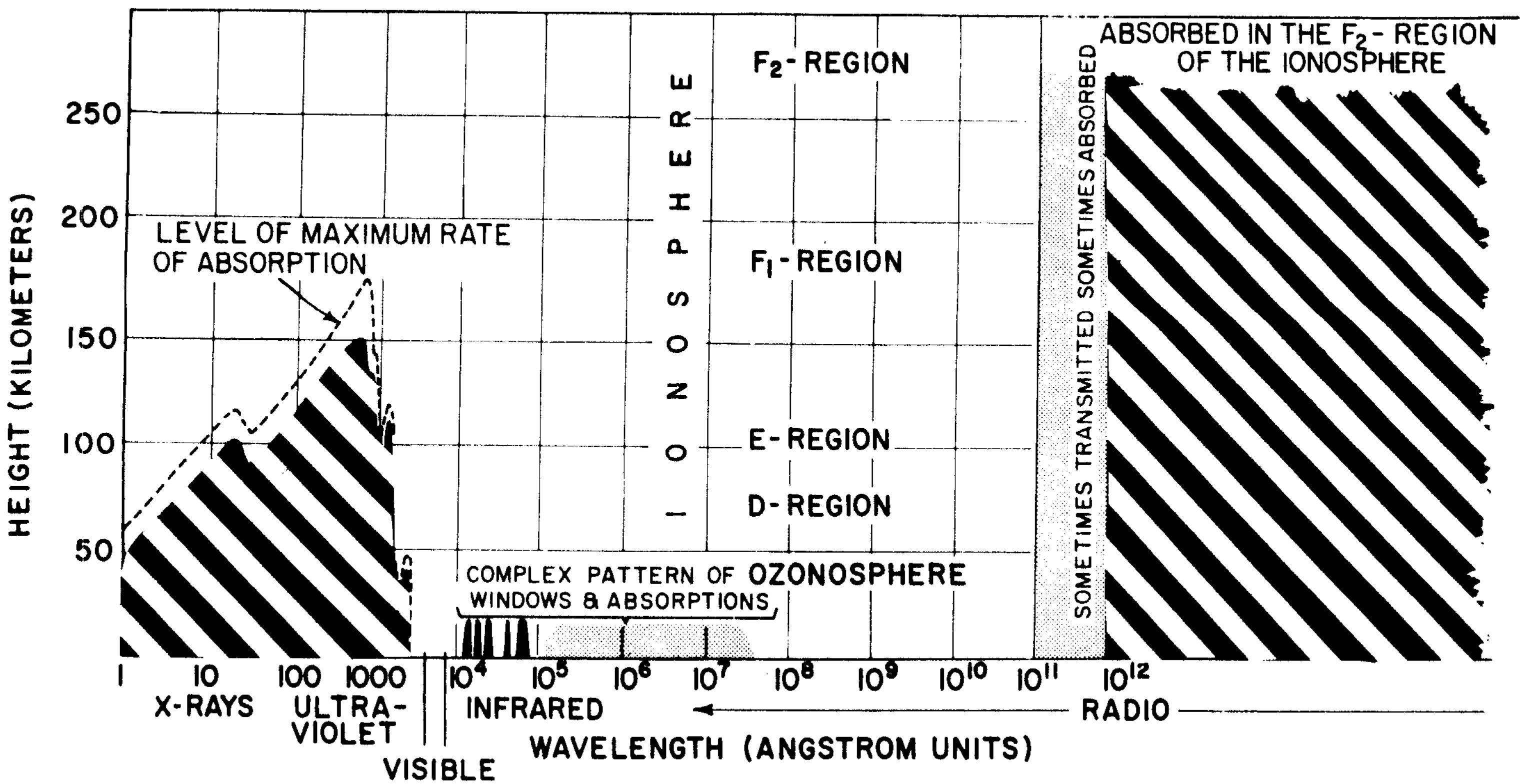


ELECTRON DENSITIES OF THE IONOSPHERE AS A FUNCTION OF ALTITUDE
AND EXTRAPOLATION TO INCLUDE WHISTLER ESTIMATES

FIGURE 3

GREAT RADIATION BELTS





ABSORPTION OF ELECTROMAGNETIC RADIATION BY THE EARTH"S ATMOSPHERE

FIGURE 5

TYPICAL VEHICLES

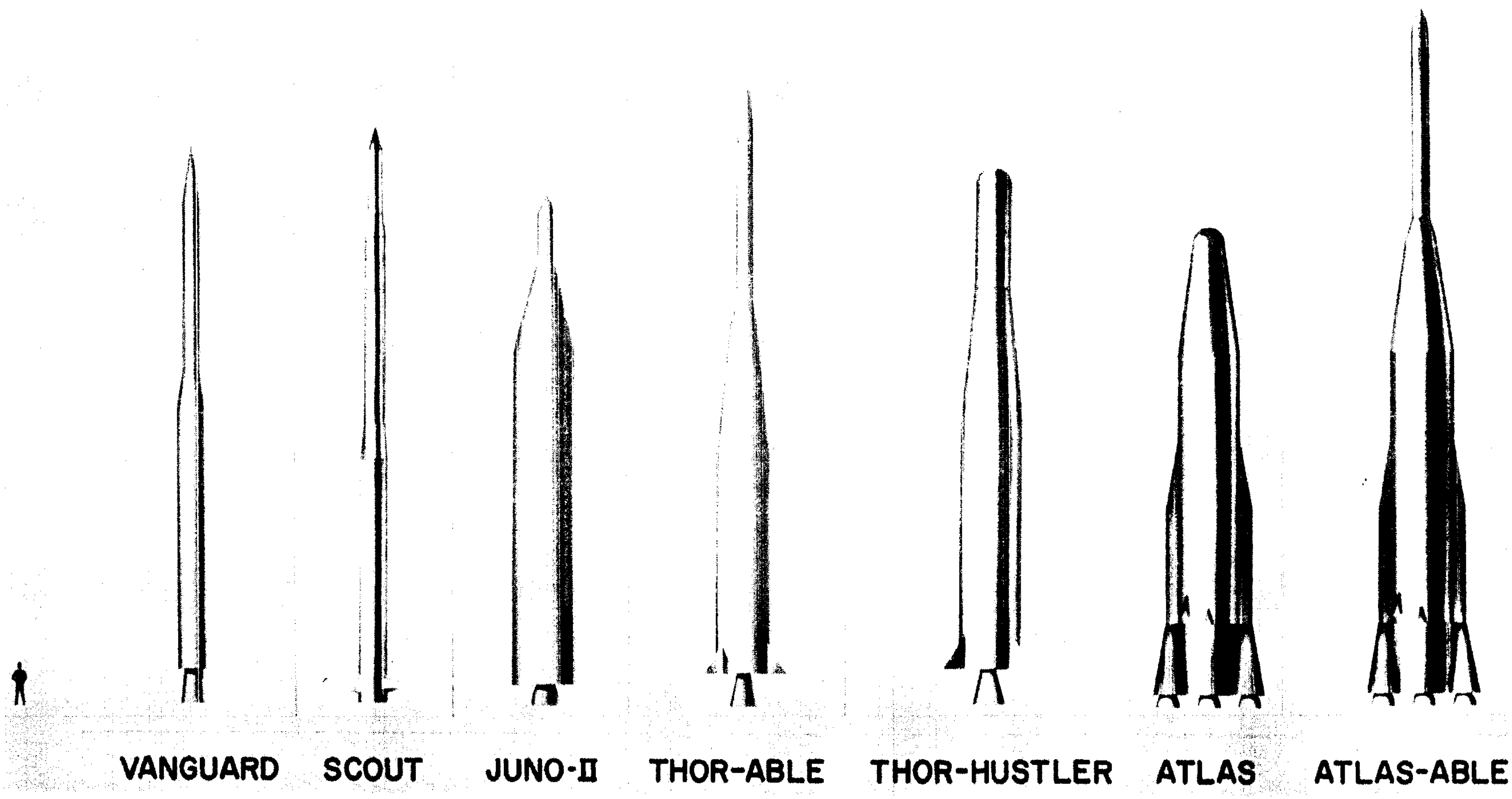
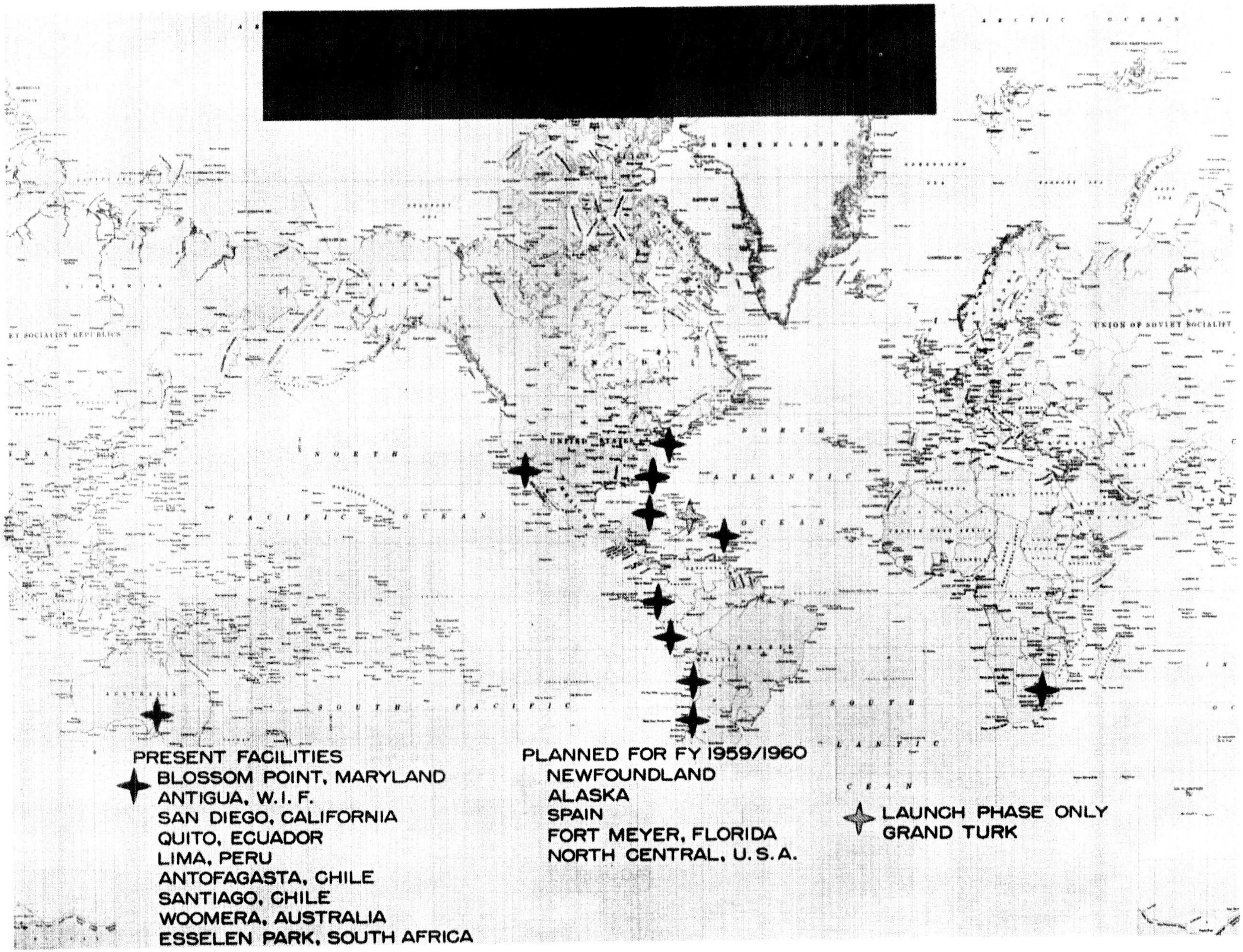


FIGURE 6.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PRESENT FACILITIES
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SAN DIEGO, CALIFORNIA
QUITO, ECUADOR
LIMA, PERU
ANTOFAGASTA, CHILE
SANTIAGO, CHILE
WOOMERA, AUSTRALIA
ESSELEN PARK, SOUTH AFRICA
PLANNED FOR FY 1959/1960
NEWFOUNDLAND
ALASKA
SPAIN
FORT MEYER, FLORIDA
NORTH CENTRAL, U. S. A.
LAUNCH PHASE ONLY
GRAND TURK

FIGURE 7

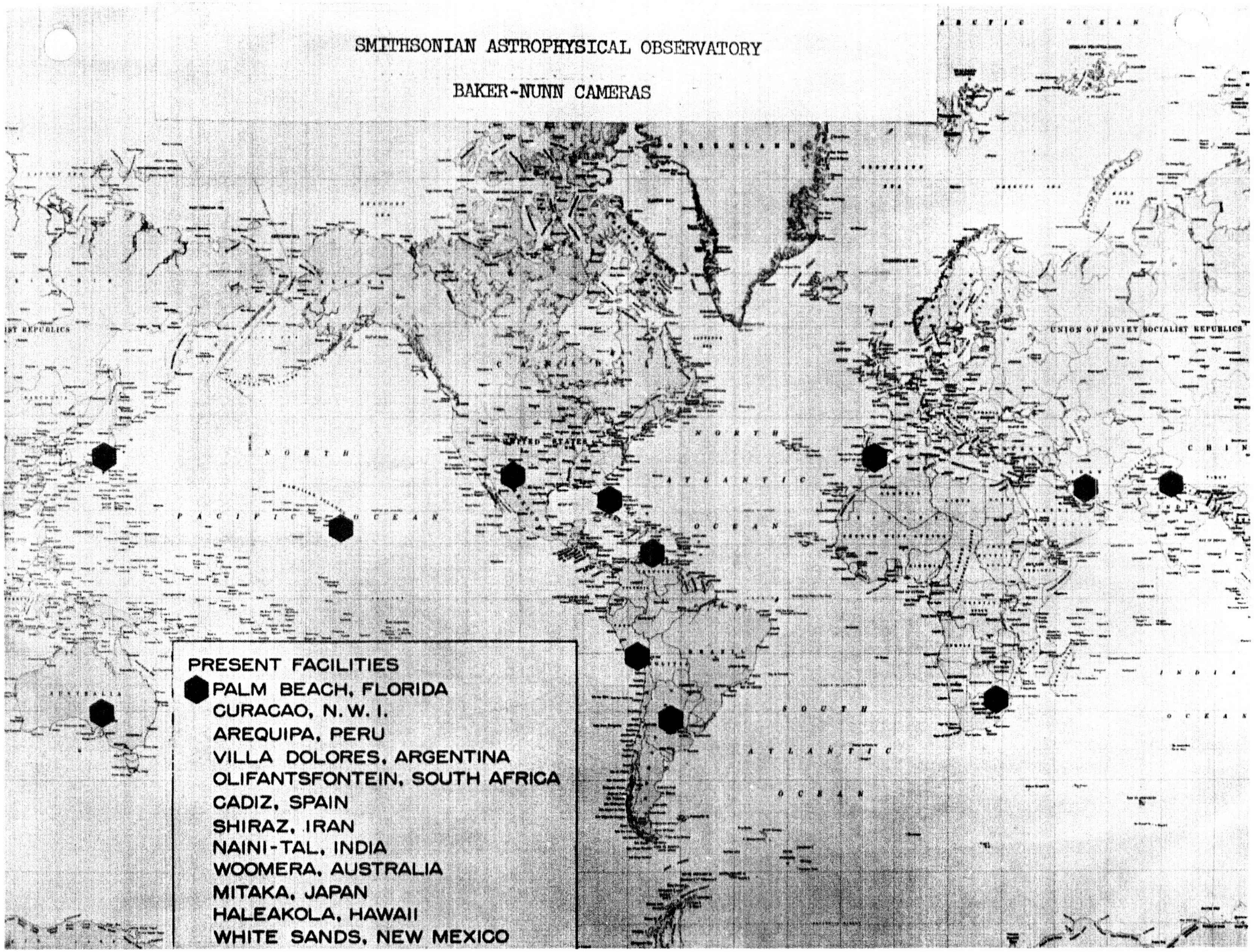
SMITHSONIAN ASTROPHYSICAL OBSERVATORY
BAKER-NUNN CAMERAS
PRESENT FACILITIES
PALM BEACH, FLORIDA
CURACAO, N. W. I.
AREQUIPA, PERU
VILLA DOLORES, ARGENTINA
OLIFANTSFONTEIN, SOUTH AFRICA
CADIZ, SPAIN
SHIRAZ, IRAN
NAINI-TAL, INDIA
WOOMERA, AUSTRALIA
MITAKA, JAPAN
HALEAKOLA, HAWAII
WHITE SANDS, NEW MEXICO
NORTH PACIFIC OCEAN
NORTH ATLANTIC OCEAN
SOUTH ATLANTIC OCEAN
INDIAN OCEAN
ARCTIC OCEAN
UNION OF SOVIET SOCIALIST REPUBLICS

FIGURE 8

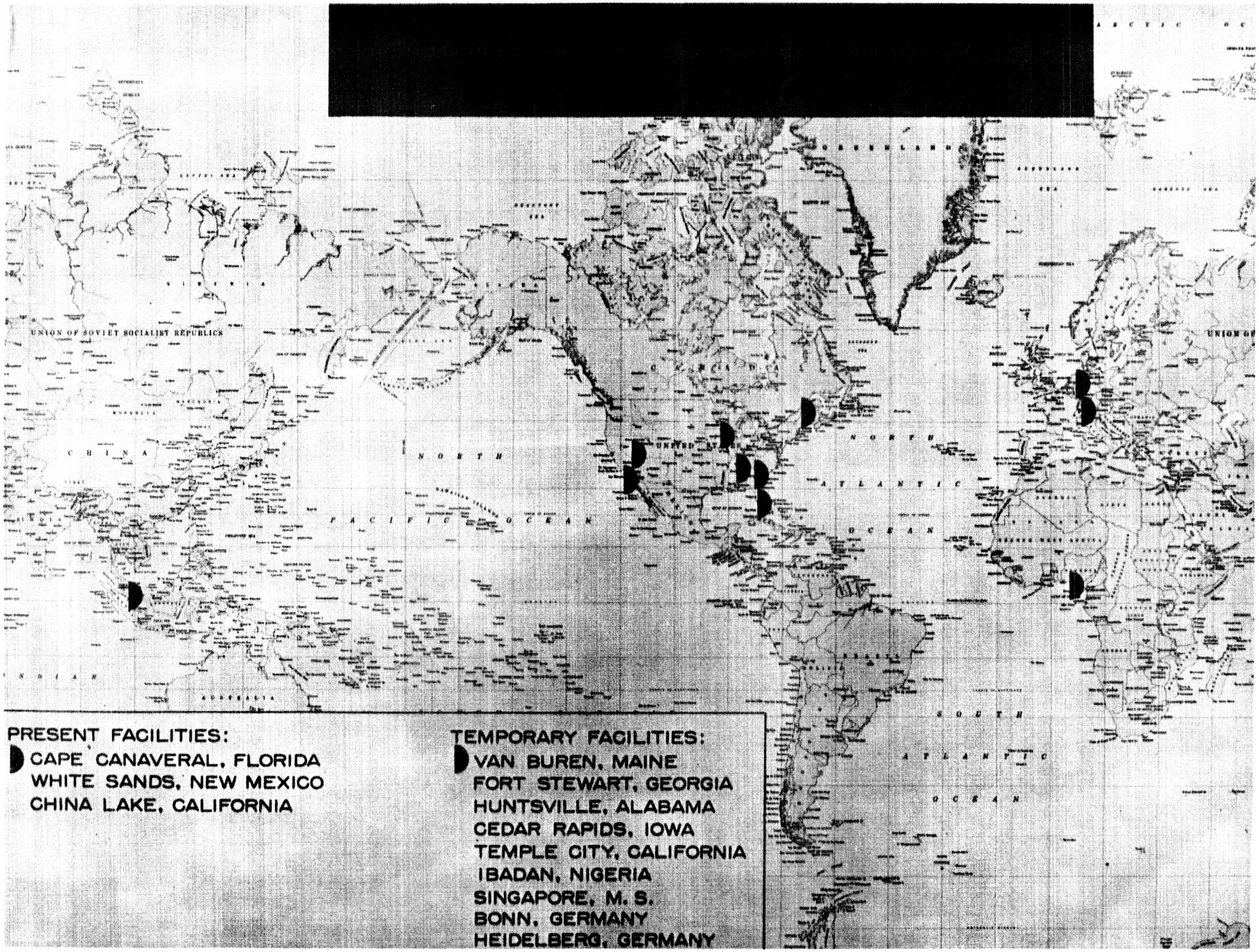
[redacted]
UNION OF SOVIET SOCIALIST REPUBLICS
CHINA
NORTH
PACIFIC OCEAN
NORTH
ATLANTIC
OCEAN
SOUTH
ATLANTIC
OCEAN
PRESENT FACILITIES:
CAPE CANAVERAL, FLORIDA
WHITE SANDS, NEW MEXICO
CHINA LAKE, CALIFORNIA
TEMPORARY FACILITIES:
VAN BUREN, MAINE
FORT STEWART, GEORGIA
HUNTSVILLE, ALABAMA
CEDAR RAPIDS, IOWA
TEMPLE CITY, CALIFORNIA
IBADAN, NIGERIA
SINGAPORE, M. S.
BONN, GERMANY
HEIDELBERG, GERMANY

FIGURE 9

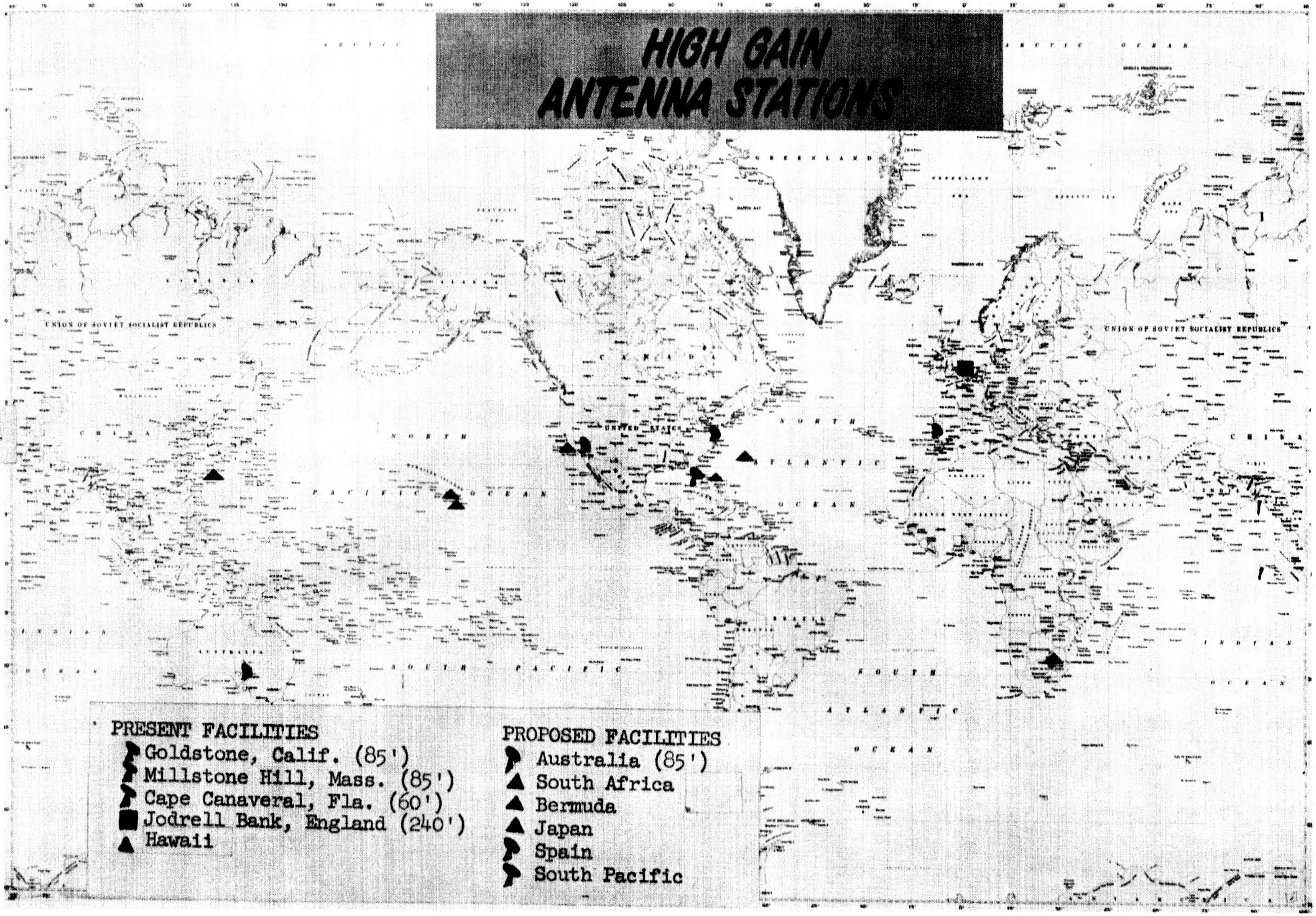
HIGH GAIN ANTENNA STATIONS
GREENLAND
CANADA
UNITED STATES
NORTH ATLANTIC OCEAN
NORTH PACIFIC OCEAN
SOUTH PACIFIC
SOUTH ATLANTIC OCEAN
UNION OF SOVIET SOCIALIST REPUBLICS
CHINA
INDIAN OCEAN
ARCTIC OCEAN
PRESENT FACILITIES
Goldstone, Calif. (85')
Millstone Hill, Mass. (85')
Cape Canaveral, Fla. (60')
Jodrell Bank, England (240')
Hawaii
PROPOSED FACILITIES
Australia (85')
South Africa
Bermuda
Japan
Spain
South Pacific

FIGURE 10

TRACKING AND DATA ACQUISITION FACILITIES NOW AVAILABLE

Facility	Application	Number/Type	Functions
Minitrack Network	All Satellites Using 108 or 40 mc	11	Radio Tracking and Data Acquisition Network
Baker-Nunn Stations	Satellites	12	Precision Optical Tracking and Computing System
Microlock Stations	All Satellites	6 to 12	40 and 108 mc Radio Doppler and Telemetry Stations
Moon Probe Stations	Pioneer III	2 - 85' Antenna 2 - Small, Temporary	960 mc Lunar Probe Tracking and Data Acquisition Stations
Moon Probe Stations	Pioneer I and II	1 - 60' antenna 2 - Shared 3 - Temporary	108 mc Lunar Probe Tracking and Data Acquisition Stations
Discoverer Stations	Discovery Satellites	6 - SCR 584 Mod. II 2 - 60' Antennas	240 mc Tracking and Data Acquisition Stations
Apogee Moonwatch Stations	All Satellites	6	Visual Observation Stations

Figure 11